Science News

IV

Edited by

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Contents

Editorial 6

Life at High Pressures *by* Professor J B. S Haldane, F.R.S 9

The Jet Locomotive *by* W. F Coxon 30

Science and Crime Detection *by* Keith Simpson 36

Noises from the Sun and Stars *by* Gabriele Rabel 53

Chemical Front 60
Comment—Silicones—BAL—Chromatography—Synthetic Penicillin

De-icing of Ships *by* G. van Praagh 72

Oceanography *by* G. E. R. Deacon, F.R.S 77

Medical News 104
The Cure for Tuberculosis—Paludrine for Malaria—Stammering—Prefrontal Leucotomy

Cosmic Rays *by* G Rabel 114

The Control of Flowering *by* Professor Eric Ashby 127

Friction *by* F. P. Bowden 139

Glossary 167

Index 169

About Our Contributors 170

Editorial

Some time ago, at a conference in London, speakers deplored the fact that the scientific journalist is an animal on the verge of extinction. "All the professional writers on science for newspapers in the British Isles could get into one taxicab," one of them said, and went on to remark that he knew of no recruits among the younger men to the task of presenting scientific information to the general public. Various reasons for this were discussed. Perhaps one of them is that there is little opportunity for free-lance work in science reporting, and consequently people have little chance of discovering their abilities in this field and gaining experience in it

It is therefore worth noting that *Science News* does consider MSS sent in out of the blue, and only a part of each issue is in fact made up of specially commissioned articles We are always glad to have these unsolicited manuscripts, but we try to submit them to standards of simplicity and extreme intelligibility which an orthodox technical or scientific paper does not have to pass Our demands are not as stringent as those of a national daily newspaper have to be. They are really nothing more than the rules of good teaching.

Every scientific subject, without exception, can be made clear to the layman. All the ideas of science are basically simple and understandable by the average brain. In text-books and journals they are, however, usually wrapped up in technical language, and presented in a very condensed form which assumes that the reader already knows a great deal and is prepared to struggle for more The job of the science writer is to unwrap, and to make the acquisition of knowledge a pleasure rather than a struggle, and this means translating all the technical terms into common speech, and expanding the discussion of the facts and ideas by explaining

their background. Provided an author really understands his subject himself and has enough space to write his expanded discussion in simple words, there is nothing under the sun which he cannot clarify and teach. Unfortunately some people imagine that popularisation means missing out even the amount of explanation a scientist expects, and merely stating a few facts in technical jargon They usually begin by making the cardinal psychological error of frightening the reader with "Of course this is very difficult to explain . " Never admit your inadequacy in this way: let the reader find it out.

If you really understand your subject you can explain the problems facing scientists in it, why they are interested in these matters and how they try to solve them You can also discuss the results and the ideas as part of a wider whole, how they affect the rest of science, and mankind in general. The discovery of a new drug like penicillin, or of a new atomic particle like the meson, is worthy of more than a bald statement, it needs an account of how the discovery came to be made, what other research it foreshadows, its effect on biological or physical theory, its practical importance. In this way the lay reader begins to appreciate it as a sensible job of work with some meaning for him, instead of finding it incomprehensible magic.

It is very important in writing to be concrete—abstract generalisation is usually vague and fills the reader's head with nothing but damp mist Facts and actual simple experimental observations come first, and the generalisations then spring naturally and clearly from them. Even more important is to write in everyday or conversational English. The man who puts down "consume" when he means "eat," "contemporaneous" instead of "present-day," "disintegrate" in place of "break up," is setting his readers a double task. They have to translate his article into understandable language before they can get to grips with its actual subject matter Finally, try to imagine the sort of

questions a lay reader will be likely to ask you, and answer them in advance in your discussion of your subject.

In this issue of *Science News*, Professor J B. S. Haldane describes the work he did during the war on diving. Dr. G. E. R. Deacon gives the first popular outline of the modern science of the sea, a subject which he has played an important part in building, Dr. van Praagh outlines simple experiments he has conducted on ice formation. (This, incidentally, is also an important peacetime problem every winter, when the conductor rails ice over, and suburban electric trains are brought to an untimely halt.) Dr. Keith Simpson expertly describes how the crime wave is being fought; Professor Ashby brings some of the latest news in botany; and in addition there are brief accounts of progress in physics, chemistry and medicine. As usual, we include a glossary and index

Life at High Pressures

BY PROFESSOR J.B.S.HALDANE, F.R.S

MEN go down to considerable depths under water for both peaceful and warlike purposes As you go down the pressure increases Suppose you have a vertical tube whose cross section is a square metre full of sea water The amount of water in every 10 metres of this tube weighs as much as would all the air in it if it went up, say to a height of 50 kilometres, above which there would be only a few milligrammes. This means that for every 10 metres, or 33 feet, that we go down, we get an extra atmosphere's pressure Thus the total pressure at the surface is 1 atmosphere, at 33 feet 2 atmospheres, at 330 feet 11 atmospheres, and so on.

Now a man can cope with this pressure in two ways. He can get into some kind of metal box which will resist the pressure, while the pressure inside the box stays at one atmosphere The box may be a sphere, like that in which Beebe went down half a mile It may be a submarine Whether any submarines can dive more than about 500 feet without caving in is a secret Or it may be an armoured diving dress with more or less flexible joints. Such dresses work well enough near the surface, but not so well at great depths. The reason is simple enough. The shoulder joint of a suit of armour must be a good deal broader than that of an ordinary greatcoat. I doubt if it could be cut down to an area of less than half a square foot. But let's suppose it has been cut to 50 square inches At 330 feet, or an excess pressure of 10 atmospheres, the pressure on the joint is $10 \times 50 \times 15$ pounds, for an atmosphere is 15 pounds per square inch That makes 7,500 lb, or about 3 tons 6 cwt. Suppose by some miracle of lubrication the coefficient of friction were cut down to 1 per cent, this would

mean that the diver would have to exert a force of 75 lb. whenever he wanted to raise his arm And things would be worse at greater depths. There is no future in armoured suits. There is a future in pressure-tight chambers where the diver can sit comfortably and operate machinery by electrical control So far however such chambers have been most successfully used with a telephone, to direct operators in the parent ship as to how to use a grab or where to place an explosive charge.

The other way to cope with pressure is to submit to it. In this case one must breathe air at the same pressure as the water outside. The reason is simple. Supposing a man with air at one atmosphere's pressure inside his lungs were suddenly subjected to water pressure at 330 feet, and suppose that on a life-size X-ray photograph his lungs cover half a square foot. At 330 feet he would have over 3 tons of pressure on the outside of his chest and none inside. It would be a quick death The surprising thing is that balanced pressure is completely harmless, and is not even felt. Our tissues transmit pressure as smoothly and evenly as if they were completely fluid. They give to an extent which can barely be measured. Actually your volume is reduced by about one twenty-thousandth for each atmosphere. But you don't notice this any more than you notice the 15 lb. pressure on each square inch of your skin in everyday life.

on his back. A glass window is screwed into the front of his helmet. I had to reduce my moustache from Kaiser Wilhelm's size to nearer Hitler's size because it used to get caught in the screw thread. Then he goes down a ladder for six feet or so, after which he usually transfers to a rope with a lead shot at its bottom. Meanwhile air is sent down to him. The air must be delivered at a pressure equal to that of the water round him. This is easily achieved with a pump if he is only down 30 feet or so. But if he is at 300 feet the air must be compressed to ten atmospheres pressure, that is to say into one-tenth of its volume. This needs specially designed pumps and either several teams of very powerful men taking spells on them, or better a small motor with its exhaust well away from the air intake. The modern tendency is to replace the pump by a battery of compressed air cylinders ('bottles', the Navy calls them). If so some other gas mixture can be used instead of air.

The hose pipe is armoured with wire spirals between layers of rubberised cloth, and goes to his helmet through a non-return valve. This is an essential safety device. If the airpump fails and the valve starts leaking backwards, the water pressure forces the diver up into his helmet. His blood and much of his flesh go up the hose pipe, and all that is left in the dress are his bones and some rags of flesh. This has happened. But normally he gets a good stream of compressed air which inflates his dress until, in spite of the lead weights, his net weight is only a few pounds. He adjusts this by opening or closing the screw of the exit valve in his helmet, no more thinking about it than a cyclist thinks of how to balance his machine.

In warm water one can wear a dress coming down to the waist only. But the main other type worth mentioning is the self-contained. Here the diver takes his own air supply with him in steel bottles. The dress may be as described above, but the men who went into enemy ports during the war wore skinfitting dresses and breathed through a mouthpiece into a rubber bag which the Americans call a counter-

lung, because it expands when the lungs contract, and conversely. If the diver is supplied with pure oxygen and has a canister of soda-lime mixture in the counter-lung to absorb the carbon dioxide which he breathes out, it is obvious that he need not form any bubbles. It is also obvious that if you are trying to fix a time-bomb to the bottom of a German battleship you have a fair chance of dying anyway, but this is considerably increased if you produce quantities of bubbles. Even if there is no enemy near, compressed oxygen will last you about ten times as long as the same volume of compressed air.

The Davis submarine escape apparatus is the simplest form of diving apparatus It consists simply of a counter-lung with a small oxygen cylinder and soda-lime canister, and a mouth-piece. It is meant for getting out of a submarine, but has often been used to do a job of work.

My main job during the war was to tackle the physiological dangers to which divers and men trying to escape from submarines were exposed, apart from any enemy action I didn't even try to tackle all of these. And I was only one of a number of scientists on the job, some under my direction, others taking orders from the Royal Naval Physiological Laboratory, an excellent institution established during the war, and the Medical Research Council. Apart from the Navy, we got invaluable help from Messrs. Siebe Gorman & Co, the well-known makers of diving dresses, and I certainly owe my life to the reliable nature of their products.

A lot of our work was done "in the dry" in compressed air, for many of a diver's troubles are simply due to the pressure, and you can give good imitations of them and find out how to prevent them, without going under water. Most of our "dry" work was done in Siebe Gorman's Chamber No 3 (see Plate 25) This is a steel cylinder like a boiler. It lies on its side and is 8 ft. long and 4 ft. in diameter. So three people can sit in it, but one can't begin to stand up. At one end is a steel door. This opens inwards

and has a rubber flange, so once there is a good air pressure inside, it is extremely tight. There are some glass plugs in the side and the door, which act as windows, and of course inlets and outlets for air, but no lamps or telephone inside. One communicates by a code of taps, by shouting, or by holding messages to the window. This factory has no water more than 20 feet deep, so to simulate a deep dive we used a steel tank about 6 feet across and 10 feet high. It had about 7 feet of water in it, in which the diver could stand, sit, crawl or lie. There was a pulley with a weight so that the diver could do measured amounts of work, and a slate to write on. Above this was an air space where the attendant sat on a shelf with his feet in the water. He kept an eye on the diver, and could haul him or her up with a rope if he or she lost consciousness.

By letting compressed air into the air space, one could put any desired pressure on the water, and we were able to reproduce all the symptoms reported in genuine dives. There was one extra symptom. Divers are tough men, but some of them got a genuine claustrophobia in this tank. They longed for the wide open spaces of the sea bottom. Certainly it was a queer experience to wait under water in this rather dark tank, knowing that one might lose consciousness at any moment, and perhaps wake up with a broken back, conceivably not wake up at all, and to look out through the very small window at butterflies, bicycles and other familiar things. My father called this tank the Chamber of Horrors. The Navy called it the Pot.

Such was our set-up. Now for the dangers which we had to investigate. The first, and least important, group arises from very rapid changes of pressure. One feels pressure changes in one's ears, because if the pressure on the two sides of the drum is unequal, it is strained. The drum is a thin membrane across a bony passage which goes from the outside to one's throat, and incidentally was a gill-slit when our ancestors were fish. The air gets freely enough to the drum from the outside, unless, indeed, one has a lot of

After these preliminaries we come to the real dangers. They arise from the fact that all gases dissolve in liquids, and the amount dissolved is proportional to the pressure. Our body consists mainly of liquids, so at ten atmospheres there is, after a sufficiently long stay, about ten times as much nitrogen in solution in our bodies as normally. Our tissues use oxygen and make carbon dioxide, so these gases do not obey the rule so accurately.

All gases are poisonous. This has not yet been proved, but I believe it to be true, and hope to make it plausible to my readers. All solids and liquids are not poisonous, because they do not dissolve in our blood and tissues. Thus a lead shrapnel bullet under the skin is not deadly, though lead acetate is so, and we can swallow paraffin oil with safety or even advantage, though the same amount injected into a vein would be fatal. In particular, nitrogen is a poison.

If one is compressed to ten atmospheres one feels very abnormal. The feelings are rather like those of alcoholic intoxication, but perhaps more like those of mild intoxication with petrol vapour or nitrous oxide. I have little control over my thoughts, and my consciousness is invaded by childhood memories, and nonsensical words which seem to me very important. Another subject was first ashamed at finding a little nasal secretion on her hand, then ashamed at her shame, and finally convinced of the necessity either of divine grace or the extinction of her personal identity. At atmospheric pressure she is a materialist. Others merely "felt awful" or thought they were dying. A few were elated. I had no abnormal sensations, except occasionally a curious velvety sensation on the lips, first noted by Dr. Negrin, the former Spanish Prime Minister, who was compressed with me on one occasion. Others said that everything felt like ivory or that their fingers felt like bananas. A few saw things as if through a white mist.

For practical purposes what matter are disturbances of behaviour. We used two tests. One consisted of putting

steel balls into holes, lifting them with the fingers and with special instruments. The test was originally designed to weed out the clumsier candidates for the profession of dentistry. One compared the scores at one and ten atmospheres. The deterioration was quite slight. A good scorer was still good under pressure. But a number of the subjects were detected cheating, for example by using both hands. The other test was doing multiplications such as 7486×5137 as quickly as possible. Here the deterioration was enormous. Instead of getting about nine sums out of ten right, I usually got about three. One distinguished Fellow of the Royal Society put down two figures in five minutes, one of which was wrong, and said he thought it was a bloody silly test. The main difficulty with such tests was that the tester was usually as intoxicated as the testee, and often forgot to press the spindle of his stopwatch, or to take proper notes.

Captain Behncke, of the U.S. Naval Medical Corps, first showed that these symptoms disappear if a mixture of four volumes of helium and one of oxygen is breathed, that is to say the nitrogen in air is replaced by helium. Case and I showed that hydrogen is equally effective. We made up a mixture of one volume of air with nine of hydrogen. *This contains only 2 per cent of oxygen.* But at ten atmospheres it contains as much oxygen per cubic inch as air at atmospheric pressure, and as much oxygen is taken up by the blood going through the lungs. So it supplied all the oxygen we needed. On the other hand there was not enough oxygen in it to render it explosive. So it was safe to store it in a cylinder, whereas with a possibly explosive mixture there is a chance that the friction as it leaves the cylinder may set it off. The moment we switched over from air to helium-oxygen or hydrogen-air we felt more normal within a few seconds, and were capable of doing arithmetic within one or two minutes.

A Swedish engineer called Zetterström independently, though slightly later, discovered that hydrogen was as good

as helium. He used a mixture of four per cent of oxygen with the gas, consisting of three volumes of hydrogen to one of nitrogen, which is made by "cracking" ammonia. He also used a nitrogen-air mixture for switching over from air to the mixture used at great depths, so that at no time was the mixture in his suit explosive. With these mixtures he descended to a depth of 450 feet, and answered the telephone rationally. Unfortunately he was pulled up by means of a platform, and owing to some mistake, which has not been very adequately explained, this was done too rapidly, and he died of bubbles in the blood, in the way which I explain later. Since helium is almost a monopoly of one of the great American oil trusts, it will doubtless continue to be boosted. But hydrogen is probably as safe as helium, and certainly vastly cheaper Zetterström's death was due to an error committed at the surface.

It is a surprising fact that argon has the same effects as nitrogen, and at somewhat lower pressures. As it does not combine with anything, this makes it fairly clear that the narcotic effect is simply due to nitrogen and argon getting in the way of the normal processes in cells. If so, it is reasonably sure that hydrogen and helium would have similar effects at very high pressures, and neon at an intermediate one One minor point is worth noting. The narcotic action of nitrogen was discovered on men. Baboons compressed to 15 atmospheres showed no abnormal behaviour. An eminent psychologist (who had not himself been under high pressure) gave a psychological explanation of the effect of compressed air on human behaviour. As a mistake under water can easily be fatal, the baboons and the psychologist between them probably have some deaths to answer for.

Oxygen is a poison of quite a different sort. There are two kinds of symptoms. At high pressures the symptoms are nervous. One ends up with loss of consciousness and a convulsion quite like an ordinary epileptic fit, except that occasionally the muscular contractions are violent enough

to break a bone. Before the fit there are almost always vague feelings of discomfort. Usually, though certainly not always, the muscles of the face stiffen and begin to twitch. Some people get uncontrollable hiccups. There is never any confusion like that produced by nitrogen. Unfortunately certain people often get no warning signs, though I generally do so myself.

At pressures below three atmospheres one may last long enough without a fit to develop lung irritation. This begins as mild coughing, followed by pain, and develops into a pneumonia which may be fatal. However it is of very little practical importance. At 2½ atmospheres (50 ft.) I did not even start coughing for 3¼ hours, and when I knocked off after 4½, I had nothing worse than a chest pain which lasted for a day or two. Dr. Case had a very similar experience. Most people would get a fit long before this.

The most curious fact about oxygen poisoning is that the effects on the central nervous system are extremely variable in their time of onset, both between different people, and in the same person from day to day. Even after I had had two severe fits and crushed some vertebrae, I remained more resistant than the average. But after about a hundred experiments, in half of which I had had some nervous symptoms, I became so sensitive that I began to twitch after breathing oxygen for five minutes at atmospheric pressure. Of course this may be attributed to hysteria, a conditioned reflex, or some such cause. But as I started breathing air through a mouthpiece, and nobody told me when the oxygen was turned on, neither explanation seems very likely. Other people varied irregularly. My wife breathed oxygen at 90 feet pressure on 17 occasions. On one she lasted for 88 minutes and knocked off with warning symptoms. On another she had a fit after 13 minutes. Her other times were intermediate.

Besides this great variation in the same person, there are differences between different people. Some people always

seem to be sensitive, and are clearly no good for underwater work involving oxygen breathing. It is very important to weed such people out. There is no way of predicting beforehand how anyone will behave Men who had been on several commando raids or got a G.C. for dealing with mines under water crumpled up, when a woman who screams on rather slight provocation, or an elderly and rather flabby professor, were quite happy. Worse still, one could not predict very accurately from experiments in air to what would happen under water. I had one of my fits for this reason.

One of the naval ratings who was being trained in the use of oxygen under water was a boxer. While coming round from a fit he asked "Who did that?" As he was lying down and someone was wiping him with a towel he probably thought he had been knocked out. The attendant answered "Oxygen Pete." Oxygen Pete caught on. Would-be oxygen divers were first tested in No. 3 chamber. In one corner of it someone wrote "Oxygen Pete sits here." If several people had fits on the same morning people said "Oxygen Pete's in form today," and if one lasted unusually long one boasted of having got the better of him. I suppose a number of gods and devils started their mythological lives in some such way in the past. Fortunately Oxygen Pete arrived on the scene too late to be incorporated into a religion

The oddest thing we found out was that oxygen has a taste. The textbooks say it is a colourless, inodorous, tasteless gas At six atmospheres I described its taste as "like dilute ink with a little sugar in it" My colleague Dr. Kalmus described it as "like flat gingerbeer." Anyway it is both sweet and sour. Of course this is an example of what Hegel and Engels called the transformation of quantity into quality. In pure oxygen at 6 atmospheres there is 30 times as much oxygen in a cubic inch as in air at one atmosphere. And 30 times as much dissolves in a cubic inch of water. You don't taste sugar or salt dissolved

in water till it reaches a certain concentration. Nor do you taste oxygen. Still it is rather striking that a gas with no sensory qualities at ordinary pressures develops them at high ones. In the same way ammonia and methane have quite a colour if you look through enough of them. The first men to go to Saturn (and by the way they will have to wear self-contained diving suits) will notice this fact, for a spectroscope shows that the atmospheres of the outer planets are coloured by these gases.

The greatest of all dangers to divers remains to be described. An average man has about a litre of nitrogen dissolved in his body. If he stays for six hours or so in air at two atmospheres, he will have two litres, and so on. It soaks in rather slowly. Organs like the brain and liver, with a good blood supply, take it up quickly, but those, like the joints and fat, with a poor blood supply, take some hours to fill up. Now if you have a liquid in which a gas is dissolved at a high pressure, and suddenly lower the pressure on it, the gas comes out of solution and forms bubbles. Ginger beer and champagne contain carbon dioxide under pressure, and froth when a bottle is uncorked.

Much the same happens in a man or woman. If you have been for an hour at a hundred feet, that is to say at a total pressure of four atmospheres, and incautiously screw up the escape valve of your diving dress, it inflates until you suddenly leave the bottom. You shoot up to the top, and within a few seconds you are black in the face, and unconscious. If the attendant undoes your dress, you will die in a few minutes, and the post-mortem examination will show your bloodvessels full of froth. As your heart cannot drive bubbles through your capillaries, you die of oxygen want. In such a case the only thing to do is to open the air vent and drop you back to the bottom again. The bubbles are at once compressed to a quarter of their size, and soon begin to dissolve again in your blood. A number of lives have been saved in this way.

Supposing, instead of coming up very rapidly, you do

so in two or three minutes, the blood will have time to unload its spare nitrogen in your lungs on the way up. For on an average every drop of blood goes through your lungs about twice a minute. But within a short time you will be in severe pain. The commonest places for this pain are the joints, but one can get them elsewhere You may also become paralysed. The joint pain is called "bends" because when one has it in the knee or elbow one finds it difficult to straighten the limb concerned. The pain has been described as unbearable. I don't believe it. I have never seen anyone sweating with pain from bends, which I take as a good rough sign of severe pain. But it is quite enough to stop one working efficiently, and may go on for days.

Bends are probably due to bubbles in the bags of synovial fluid which buffer the joints. A bubble in the nervous system is more serious. I have only had one This was in the lower part of my spinal cord. For several days I had a burning pain in the skin of my buttocks. This gradually died down to a tickle, combined with a loss of ordinary sensation. Both of these are still there after six years. If I had lost most of the sensation from my right hand, the result would have been more serious. Other people have had bubbles which interrupted the paths to muscles, and therefore caused paralysis, and some have died from this cause.

If one is decompressed under conditions which just do not cause bends, a very common symptom is itching, often combined with redness of the skin. Nobody knows how this arises, though there are several guesses

My father, Dr. J. S. Haldane, worked out the method which is universally used to avoid bends· He found that however long an animal or a man had been exposed to compressed air, it is always safe to halve the pressure. Thus even after many hours at 33 feet of sea water, or two atmospheres, one can come to the surface at once. But after a long time at 66 feet, or three atmospheres, a

is only safe to come up to 16 feet, or 1½ atmospheres. Then one waits until one has got rid of some of the excess nitrogen, comes up a further stage, waits again, and so on. For example after half an hour to an hour at 175 feet, one comes up to 70 feet in 3 minutes, stops 3 minutes at 70 feet, 3 at 60 feet, 7 at 50 feet, 10 at 40 feet, 20 at 30 feet, 30 at 20 feet, and 35 at 10 feet The total time spent in ascent is 181 minutes, or perhaps three times as long as one spent on the bottom.

Sir Robert Davis, of Siebe Gorman and Co, speeded up decompression by the following device. The diver comes up to the first stop, and then gets into a chamber like a diving bell with an open bottom. An attendant helps him out of his dress, and gives him oxygen to breathe. In consequence almost all the nitrogen in the blood passing through his lungs comes out of it, and he can be decompressed a lot quicker than if he breathed air.

My father also recommended the use of mixtures of air and oxygen under water, so that the diver would take up less nitrogen. However no systematic work had been done with such mixtures. The matter became urgent in 1943. It was foreseen that when we captured ports from the Germans they would leave behind them mines and obstacles such as sunken ships, which would have to be removed. Now you must be a very brave man indeed to hunt for magnetic mines in muddy water, especially if you have seen some of your comrades go up You must be a man of superhuman courage if you know that, if you hear a mine beginning to tick, and go up to the surface quickly, you may be paralysed for life if you are not blown to pieces. There *is another reason why you should be able to come* up quick. In an air raid on Le Havre or some other recaptured port in 1944 a man in a boat was in no greater danger than the average Londoner at the same time. But if he was under water he might be killed by the shock wave from a bomb bursting in the sea several hundred yards off. For water is so incompressible that a shock wave

must travel very much further than in air before it fades out. So divers should come up during an air raid

Clearly if the diver breathes a mixture of air and oxygen he will absorb less nitrogen than if he breathes air. Hence he can come up safely from a greater depth So one wants to cut the nitrogen down as much as possible On the other hand if he gets too little nitrogen, and too much oxygen, he will have a fit. It is safer to have a fit when clearing obstacles with a comrade ready to haul you up than when crawling under the Tirpitz. But it is not a hundred per cent safe. So my wife and I set out to find the safest mixtures to use at various depths and for various times There were some calculations to be done first, for the mixture in the diver's lungs is by no means the same as that in his bottle. Then we had to try the mixture out This meant going say to 70 feet pressure for half an hour. One of us would work while the other kept watch Then we were rapidly decompressed If there were no symptoms we repeated the experience the next day for three-quarters of an hour, and so on. If either of us got bends we generally took a day off to let the bubbles disappear.

These experiments were successful. According to the official tables, a diver who had been at a certain depth for a certain time was supposed to take forty-seven minutes to come up. We did it in two minutes without anything worse than itching, though I admit the naval officer who tried it next got a rather stiff shoulder. So the official time for an ascent from such a dive is, I think, seven minutes. But one could come up in one minute during an air raid without serious danger. The mixtures which we had tested in 1943 were used by the "P-parties" which cleared occupied ports in 1944. This was our main contribution to winning the war, though I gave a good deal of advice on all sorts of matters, from tanks to bomb-aiming, and some of it was accepted

One of these matters was escape from submarines, and here Dr. Case and I had to deal with still another gas,

carbon dioxide. Suppose a submarine is on the bottom and cannot rise. By the time this is clearly known the air is fairly foul. Now all the hatches of a submarine open outwards, so that the water pressure outside keeps them shut. They cannot be opened till the air pressure inside is equal to the water pressure outside. Men can get out of a submarine one at a time from a small escape chamber, or twenty or thirty at a time from a flooded compartment. Suppose you are at 300 feet, you let in water till the air in the compartment is squeezed into one tenth of its original bulk. You then put on your Davis apparatus, open the hatch, and ascend to the surface. At least you are supposed to.

But there will certainly be some extra carbon dioxide in the ship's air from the crew's breathing, even if the air-purifying apparatus is acting well At ten atmospheres there will be ten times as much in each cubic inch We were asked to find out how poisonous this gas was at high pressures The average man loses consciousness in about five minutes at ten atmospheres when there is as little as three-quarters of a per cent of carbon dioxide in the air breathed. This gives the same absolute amount per cubic inch as if he were breathing 7½ per cent at atmospheric pressure.

The standard set-up was an inquisitor (Dr. Case or myself) and a rabbit (somebody else, after each of us had acted as rabbit). The inquisitor wore a respirator to absorb the carbon dioxide in the air breathed. If he kept it on he had the fun of seeing the rabbit lose consciousness and finally fail to respond even when his or her eyes were touched. Sometimes however the inquisitor got so intoxicated with nitrogen that he forgot to put his respirator on after taking it off to say something. Then there were two unconscious rabbits, and an observer outside gave the order to decompress when both appeared to have taken the count.

The Admiralty also wanted to know what happened if

the water was very cold, as it is in the Arctic Ocean. So we used to lie in a shirt and trousers in a bath of water with melting ice in it until shivering became uncontrollable. This took about 15 minutes for Case, and 20 minutes for me, as I am fatter. Then we were compressed, and any gas required was added. These experiments were not appreciably unpleasant. One feels a sharp pain round the neck at the surface of the water. The rest of the skin soon gets numb. One's resistance to high pressure gases is slightly but not very greatly lowered.

Dante said that the very worst sinners were frozen in ice. They were also exposed to compressed air ("l'aër perso" is his phrase, and the pressure would reach 10 atmospheres at a moderate depth) and presumably to carbon dioxide from the flames. As one of the two people who have tried it, I can say that the great Italian poet exaggerated the discomfort of the sinners in question. I hope that if any reader has qualified for the eternal ice by the treacherous murder of a relative or benefactor, this may console him.

It now remains to draw the moral. The first point is that such experiments can and should be done on human volunteers. The Nazis did similar experiments on political prisoners and on Russian military prisoners. They killed many of them, but the information which they got was of little value. These experiments were, in fact, almost as futile as they were cruel. For the important practical question to be answered is how long a man can carry on with his work under unfavourable circumstances, not whether, after he has become unconscious, one can bring him round again. Experiments on animals are useful to show the kind of danger to be expected, but they do not tell exactly what a man can stand. This can only be done on human beings whose courage or curiosity will keep them going till they drop.

The second point is even more important, for few British people outside the B.U.F. defend the Nazi doctors. These

experiments ought to have been done before the war, and done much more methodically than we were able to do them. It is monstrous that a man should be exposed to dangerous environments, whether in war or in industry, before the most thorough tests have been done to see how men can stand up to the strain in question. And it is often possible to weed out those who will not stand up to it. Let me take an example from industry. Thousands of men and women have to inhale the vapours of solvents, for example of benzene in the rubber industry. Some fall ill, some do not. No really quantitative work has been done to find out exactly how much benzene must be inhaled to produce symptoms of given severity in, say, five per cent of a group of people. If this were done, two things might be possible. First, the dangerous concentration of benzene vapour could be much more closely defined than at present. Second, it might be possible to pick out a certain group of workers (say the very fat, or those whose kidney function was below the average) as specially likely to be injured.

Such things will not be done until our industries set up physiological laboratories like the Royal Naval Physiological Laboratory for this honourable and sometimes dangerous service. The only bodies which are likely to insist on this being done are the Trade Unions. It was, in fact, a Trade Union (the Amalgamated Engineering Union) which started me on the work which I have described here when they asked me for advice regarding some of their members who had been killed in H.M.S. *Thetis*.

Compressed air is only one of hundreds of abnormal environments in which people have to work. All of them could, and should, be investigated.

The Jet Locomotive

BY WILFRED F. COXON

THE rocket depends for its motive force on the generation of hot gases from an explosive charge. These gases force themselves out through a restricted hole in one direction and so push the rocket head away in the other, an instance of the Newtonian law that action and reaction are equal and opposite. The war saw many advances in the application of this principle. For example, on the undercarriage of aircraft were carried rockets filled with cordite, which burns at a controllable rate. When ignited, the rocket shot forward along two rails under the aircraft, and was thus given direction. The well-known Vampire and Meteor depend for their motion on a charge being fired in a combustion chamber and the hot compressed gases escaping through a backward hole, so that a forward thrust is given to the aircraft. However, attractive as the applications of jet propulsion may appear, there are limitations for ordinary purposes. A jet-propelled motor car or motor bus belching forth sheets of flame and hot gas would be a little menacing in the traffic congestion of Regent Street. In the same way a locomotive doing the same thing, and passing at high speed through a country station, would leave in its wake the effects of a miniature tornado. So jet propulsion in its direct form has its limitations for land and sea traffic.

There is however another way in which this principle can be applied. In the steam turbine a jet of steam at high pressure impinges against a paddle-shaped wheel so that the latter revolves at high speed, and the circular motion of the turbine wheel is then transmitted to drive a dynamo or the marine engine on a ship, or even a railway locomotive, as used in America. Suppose now that instead of

allowing steam to impinge on the turbine blades we allow the compressed gases of jet propulsion to drive the turbine. We then get a gas turbine engine. This is undoubtedly the form in which jet propulsion can be most readily controlled and adapted for use on land, and it is with such a gas turbine that it has been found possible in Switzerland to build a jet-propelled locomotive.

On the face of it, it seems a straightforward proposition. All you have got to do is to mix some fuel oil and air together in the correct proportion, ignite them in a confined chamber and allow the highly compressed gases to escape from a hole and impinge on a turbine blade. The latter revolves at great speed and provides the necessary motive force. But like so many other things, the transition from an attractive theoretical principle to something which is commercially practicable involves a comprehensive study by experts in many fields, and this can best be realised by considering the construction of the Swiss gas turbine used in their locomotive.

It consists of three main parts, as shown in the sketch

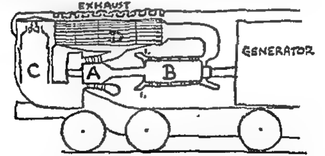


Fig 1 —Diagram of a plan of gas turbine of locomotive. Air enters compressor B from outside at 1 by a pipe not shown.

at Fig. 1. There is the Turbine A, the Compressor B and the Combustion Chamber C. There is also a heat

Exchanger D, but for the time being we need not consider this. The unit works by sucking in air from an inlet (1) compressing it in the compressor and allowing it to escape through holes surrounding the burner. An electric candle ignites the fuel mixture as it escapes so that the combustion chamber is filled with hot compressed gases. These in turn impinge on the turbine, causing it to revolve and drive a big dynamo whilst at the same time driving the compressor and so giving a further circulation of air. So if you look at this system again you will see that the motive force provided by the burning of the gas in the combustion chamber is driving three things—first the turbine, second the compressor, and thirdly the dynamo, which delivers electricity to the electric motors of the train. It is only the energy which is available from this dynamo which can be usefully employed to drive the locomotive. It is possible fairly easily to make a carefully balanced turbine so that the energy loss due purely to its revolution is very small But a considerable amount of energy is required to drive the compressor In fact so much is absorbed that in the Swiss unit the gas turbine must develop an output of 8000 h p. in order to deliver a useful output from the dynamo of 2000 h p., because 6000 h.p. is absorbed in driving the compressor itself The first necessity, to make use of jet propulsion for a locomotive, was therefore to develop a compressor which had a very high efficiency.

Now look back at the turbine itself. Obviously it must be made from metal, and you will notice that the hot gases from the combustion chamber are passing straight on to the blades of the turbine all the time that the engine is in use. In fact the turbine blades are always operating at a dull red heat. Here then was the second problem, which the metallurgists had to solve. They had to develop a heat-resisting steel alloy which was capable of operating under these severe conditions, for the life of a locomotive must be at least 15 years Even so, the temperature of

combustion in the combustion chamber is so great that if the gases were allowed to impinge directly on to the blades their life would be very short indeed. That is why if you look at the sketch you will see that not all the air handled by the compressor is used during combustion. Some of it passes round the outside of the combustion chamber, thereby lowering the temperature, and at the same time *mixing with the hot gas from the combustion chamber* so that by the time the gases reach the turbine itself the temperature is considerably reduced. In actual fact the gas temperature here is between 850° and 1100°F. Now this gas having passed through the turbine and completed its job is still warm, and to increase efficiency it is necessary to make use of this heat. The warm gases therefore pass up to the heat exchanger D, and there they circulate round the outside of the air which is being delivered by the compressor, so warming it before it reaches the gas burner. A heat exchanger, then, is merely a means whereby the heat which would normally be wasted is used for combustion.

It is perhaps useful to have some figures on the performance of this gas turbine electric locomotive, as used by the Swiss Federal Railways The guaranteed continuous output of the heat unit when measured at the generator coupling is 2200 h p. The motive force measured at the wheel rim is 29,000 lb. at the start up to 16 miles per hour. It is 17,000 lb. during one hour when the loco is travelling at 30 miles an hour, and it is 11,000 lb. continuously at speeds about 45 miles an hour. The fuel consumption at full load is about 1 lb. an hour at the wheel rim, which is about 2,000 lb. of fuel oil per hour for 2000 h p. at the wheel rim. Its maximum speed is 70 miles an hour and the effective weight with full fuel tanks is 92 tons.

Having now described some of the essential features of this jet or gas turbine locomotive, it may be as well to summarise its points of comparison with the orthodox

steam locomotive which is familiar to us all. In the first place the gas turbine engine is not yet capable of using coal, so that its use is restricted to those countries with a reasonable fuel supply of their own or where it is easily obtained. The use of this fuel of course helps a lot to reduce the foulness of the atmosphere which is particularly noticeable in a large town. As far as lubrication costs are concerned, there is a considerable saving with the gas-turbine locomotive. The consumption of lubricating oil in the orthodox steam locomotive costs round about 10 per cent of the fuel costs, whereas with the gas turbine unit, where purely rotating machinery is employed, the corresponding figure is less than 1 per cent. There again the gas turbine unit does not require to carry water for steam generation, and in a really heavy locomotive the weight of water carried may be as high as 100 tons. This also gives an added advantage to the gas turbine unit because there are no interruptions in service for maintenance such as cleaning and repairing the boilers. It is estimated that the wear of the turbine machinery is considerably smaller than that of reciprocating (sliding) machinery as normally employed in locomotive design, whilst it is estimated that the initial cost of the gas turbine locomotive lies half way between the cost of a steam locomotive and a Diesel electric locomotive. The figures are respectively £8, £14 and £22 per h p. based on pre-war prices.

As far as the future is concerned one such locomotive has been built and operates successfully in Switzerland. The same locomotive is now undergoing service trials on the French railways, whilst the British Great Western Railway have placed one on order which will include many refinements discovered as a result of service operations.

Although the gas turbine principle itself is wholly new, yet the application to a locomotive does not give us a complete locomotive entailing all new features. For example, in America the steam turbine locomotive has made many strides in recent years towards excluding the older

locomotive from the American market. At the same time the Diesel electric locomotive is a well-tried transport medium. It uses a Diesel engine to drive its dynamo, and the principle of electric transmission to the driving wheels is just the same as for the gas turbine engine.

Whether the gas turbine locomotive will be the locomotive of the future it is yet too early to decide. If the experiments which have proceeded on the design of pulverised-coal gas turbines are crowned with success the future will be very bright indeed. There seems little reason why it should not be possible to achieve an efficiency of 90 per cent for the gas turbine if it is possible to make the compressor 85 per cent efficient, because the heat losses due to the latter can be partially recovered in the gas turbine. It only requires a 4 per cent improvement in the efficiency of the turbine to give a 16 per cent improvement in the efficiency of the locomotive itself.

And lastly the metallurgists must continue their work on special steel and alloys to resist high temperatures. Between 1925 and 1940 the creep strength, which really measures the heat resisting properties of the steel, more than doubled itself owing to research by the metallurgists. Since 1940 this figure has been improved still more. This means higher working temperatures and therefore greater efficiency so that the jet locomotive of the future will really be a true representation of research and development in an extraordinarily large variety of scientific fields.

It is reported that the Admiralty are to convert all naval vessels to use gas turbines for driving the propellors. When Sir Malcolm Campbell makes his next attempt on the world's water speed record, he will be using a true "jet-propelled" speedboat.

Science and Crime Detection

BY DR. KEITH SIMPSON

A POLICEMAN on his beat is no longer the plodding pie-crust lover, the butt of the crook. The stolid pencil-licking P.C. so beloved of the crime novelist has given way to the mobile police officer, co-ordinated by wireless, trained in modern methods of crime detection and confident in his knowledge of the scientific resources at his elbow. When the P.C. blew his whistle for help in the days of "Father Brown" he was lucky if he got the brawny assistance of another lone P C. Now the cat burglar who climbs through a circuited window sets off his own alarm, causes a net of fast patrol cars, wireless linked, to close round him and seals his own channels of escape without even being seen or heard. He may leave indelible evidence of his connection with the scene of the crime, and every uniformed or plain-clothes man who bounds out of the patrol car to corner him is trained to spot and preserve these "clues."

The public is entitled to know of the vast strides which have been made by scientific advances in criminal detection, of the training that is given to the detective officer in modern schools like that at the Metropolitan Police College, at Eynsham in Oxford, Wakefield and elsewhere. The officer who comes out of these schools is trained to spot the slightest deviation from the normal—a thread of cloth caught on a window-sill, a solitary hair on a curtain, a finger print, a pinhead of blood or the smear of lipstick or saliva, a flake of paint or the merest trace of a metal dust ground off a safe-breaker's tool—any of these, or more probably several of them together, may undo the perfect crime In these days the criminal's chances of making a steady living are thin and the super-crook has virtually disappeared. Crime has been on the increase—

but so also have arrests and convictions, a fact often left out of the reproaches levelled at the police forces. Crime will always exist, but the real measure of any success the police may achieve must be their ability to cramp the free style of the habitual criminal. He may be cunning and may expend much care and thought in planning his coup, but he is matching his brain and slender resources against all the might of a vast police network with infinite resource, and an efficiency the envy of the world.

It would be sensational to say that a murderer was "hanged by a thread," an "ear of barley in the turnup of a trouser" or a trivial slip that left some vital clue at the scene of the crime, but it is rare for this to be so. Indeed the Director of Public Prosecutions would be likely to "offer no evidence" for a prosecution if it was so slender—it would not be enough to convince a jury of guilt. What does convict is a series of trivialities and the backing of circumstantial evidence that accumulates from the taking of statements—often by the score or hundred. Few people who absorb the headline "hanged by a hair" realise the patience in collecting and sifting evidence that goes on steadily from the moment a body is found to the hoped-for sequel when a suspect is charged. Let me give you an example, involving the problem of identity, one of the first obstacles to success in crime detection.

The Problem of Identity

One foggy November afternoon in 1943 two sewer men who were testing water levels in a stream which ran along *the outskirts of Luton found the naked body of a young* woman tied up in four potato sacks. She had been murdered, beaten on the head with some blunt instrument and strangled, stripped of all clothing and tipped down a bank into this stream in the fog. The police were faced with a big problem, for whilst clues to this crime were cooling and the criminal was busy covering his tracks, the C.I.D. had to set about the first big problem of all—

murders—who was she? It's easy when clothing and papers are on the body, but when there is nothing how do they set about it? This Luton sack murder was a good example of the colossal labour such a task may involve, and of the patience and industry the police may show in working on such a problem.

They hoped by publicising a photograph of the victim on local cinema screens and in shop windows, even house-to-house visits with a photograph, to get someone to recognise the victim, but nothing came of these measures. The B.B.C., the press, the Police Gazette extended this publicity all over the country. Finger print records were searched, but the dead woman's were not on record Four hundred and four missing women were either traced or excluded during the weeks which followed. Six hundred and eighty-one addresses of women were traced through poste-restantes and letters undelivered, but the police got no further. Thirty-nine visits were made to the body in the presence of police officers by people who thought that she resembled someone they knew and who was missing. Nine people identified the body in genuine error as that of four different women—none of whom proved to be the actual victim. It looked hopeless

A milk roundsman who drove past the scene each day and whose lorry had left tracks on the ground was traced and pressed for information, but he insisted that he'd have noticed the difference if he had delivered a body in potato sacks in mistake for a can of milk.

Two hundred and fifty lorry drivers whose trips to a local works took them past the stream where the body was found were interviewed separately and statements were taken from them without any useful fact emerging and innumerable people who were sure they'd heard screams or bumps or seen something suspicious in the neighbourhood at about the time of the murder were also interviewed.

Nearly three months had passed and nothing useful had emerged from these painstaking enquiries. The ordinary

man might have given up the call as utterly hopeless, but Chief Inspector Chapman, the Yard officer in charge, was no ordinary man. He pursued the enquiries tenaciously. Reviewing the mass of data he had by now collected, he one day ordered another and more searching examination of the bits and pieces of clothing found in street corners, bins and refuse dumps, and this time a real clue emerged. In the loose packing of the lining of a piece of a black coat which had been found loose in the town there was discovered a small dyers' record tag. A corresponding entry was traced in the books of one of the dyeing and cleaning firms in Luton and the Yard Inspector himself went to the address given. The door was opened by a girl of 17 who looked to him so like the victim of the crime that he felt he was near the end of his enquiries. Her mother had left home about the time of the crime. Photographs of her mother and the victim were exchanged and they proved to be so nearly alike that little doubt remained. A visit to the dental surgeon who had attended this woman resulted in the discovery of records identical with those of the dead woman, and Superintendent F. Cherrill of Scotland Yard's finger print department found a print identical with the victim's on a pickle jar in the house to which that dyer's tag had taken the C I D (see plate 9). Blood splashes were found on a door jamb of a group the same as that of the dead woman. No doubt could remain as to her identity.

The girl understood that her mother had "gone home" to her own people after a quarrel with the father. The address was located: she had not been seen there.

Meanwhile her husband had been interviewed and as his story proved unsatisfactory he was pressed for details, broke down and admitted killing his wife. He was found guilty of murder at the Bedford Assizes trial which followed.

This question of identity-proof, so important in crime detection, may run on more scientific lines as, for instance, in the classical Dobkin (Baptist Church Cellar) murder.

In that case only the dismembered and partly burned remains of a woman were found.

Sex was in no doubt, for the dried, partly dissected womb was still present Even had it not been, the female form of the bones of the hip girdle would have sufficed. An anatomist can identify the sex of even small parts of certain of the bones of the skeleton by exact measurements, since their dimensions differ slightly according to sex.

Stature was estimated from the reconstructed body, making allowance for parts destroyed by fire and for flesh. This was confirmed by the mathematical method devised by Pearson, who compiled tables relating the length of certain of the arm and leg bones to the total height of the body. These Pearson formulas are quite remarkable in their accuracy. The height of this victim, estimated at 5 ft. to 5 ft. 1 in, proved later to be correct

Age can be judged in young persons, up to about 25, from the development of the temporary (milk) and then permanent sets of teeth, and by the appearance, growth and fusion of the centres of bone formation in the gristly bones of youth. After 25 it is more difficult, though certain bone plates, like those of the skull which fuse together very late, may help. They fixed the age of this victim at 40-50.

Colouring was settled by a microscopic tag of partly burned hair found clinging to the back of the head. It was dark brown turning grey

Teeth details lay in some number in the upper jaw and both fillings and marks of wearing a denture plate were there also Further, the womb contained a fibroid tumour large enough to have caused the woman to seek medical attention

This woman was 5 ft. to 5 ft. 1 in, aged 40-50, with dark-brown hair going grey, and should have had records somewhere of both dental and womb treatment. It seemed likely she had been lying where she was found at least some 12-18 months

Police enquiries had revealed that the wife of the fire-watcher to those Baptist Church premises had disappeared mysteriously after badgering him for maintenance arrears some 15 months previously. She was 5 ft. ½ in., 47, with dark-brown hair going grey, and had, as enquiries revealed, dental data (recorded at her dentist's premises in North London) precisely identical with those of the victim. What is more, she had attended two London hospitals for womb trouble of the kind found in the victim—and had in each case refused operation. This was, no doubt, the fire-watcher's wife

Police enquiry showed that she had last been seen with her husband, quarrelling, 15 months previously Four days after she disappeared a fire broke out in the cellar of the Baptist Church and a passing police officer called the N.F.S., who drew the attention of the firewatcher to a fire on his own small premises a strange affair. The Baptist Church parson, looking around next morning, found bits of straw mattress and a fork in the cellar—but no body. He was suspicious, but went no further with the matter as the firewatcher was vague and rather offensive when questioned.

The police, who were piecing all this together, naturally felt suspicious that this fire which the firewatcher himself had failed to report occurred because he was at that time attempting to burn the body of this woman—who appeared on identity data to be his wife. They also found he had some lime in his premises—though he denied this—and lime was found sprinkled over the body. This was, in fact, Dobkin's undoing, for that lime which he intended should accelerate the disposal of the body had, of course, preserved it, and preserved among other things the bones of the larynx or voice-box. Careful examination of these showed a fracture which, for practical purposes, only occurs in strangling by the hand. This victim was, no doubt, his wife with whom he had last been seen at about the time she disappeared, four days before that mysterious fire in

the cellar, and she had died of strangling. Dobkin vehemently denied she had ever gone to the place and he also denied going back there himself after the fire, but a War Reserve Police Constable had seen him there one day and remembered shouting to him about showing a light. Dobkin was lying. He even denied knowing there was a cellar in the place, but his protestations made no impression on the jury at the Old Bailey, who found him guilty of murder. He was executed at Wandsworth Jail.

You may feel this question of identity has occupied a great deal of space, but it is not unjust that it should do so, for the identity of a victim is the first problem of any murder and its solution is vital to rapid solving of the crime. Three months elapsed before the Luton sack victim was identified, yet 36 hours was enough to solve the crime after that.

Laboratory Aids

What of the modern scientific aids to crime detection, the laboratory resources? These include many of the methods, mostly applications of quite ordinary scientific tests developed in other fields, which take crime detection inside the laboratory. It often happens that some chance observation in the laboratory has a direct and highly important application elsewhere. Penicillin was discovered because Fleming happened to notice that certain cultures of organisms were not growing properly in areas where this mould had, quite by chance, developed. The use of ultra-violet and infra-red photography in police work arose from the recognition that certain pigments or colours seemed to allow these light rays to pass through them, whereas others tended to reflect them. When different inks or paints are used to alter or fake a Road Fund car license, photographs taken with infra-red light (filtered white light) may show that some strokes of a piece of writing were done with different ink from that used for the rest of the writing. An APF.636 changed in a stolen car to ABE.680

showed as plainly as if the alterations had been made with black ink upon writing in pencil, and a long train of police enquiries was set securely on its way. It is incredibly stupid of the car thief to think that such an elementary fake would escape detection as soon as suspicion was aroused. The study of classical paintings has been much advanced by the same method, for touching up by dealers and fake signatures have thus been revealed. Espionage letters which helped to locate spies in this country during the war were detected in an instant in the same way, and so are falsified cheques and bill dates, over-painted identity batch numbers and the like.

There is a catch of course. Ultra-violet light is a strong bleacher and tends to make some pigments fade rapidly. A robbery in Surrey a few years ago was done by a man who, when arrested, had in his wallet some writing almost rubbed out. Ultra-violet light clarified the words—which proved to be the address of the robbery—but the card became too bleached to show this to the court which later sat on the case. Fortunately, bearing this in mind, a photographic record had already been made of it in its fresh state.

While on the subject of paints we should say something of a very modern instrument—the spectrograph—for this will detect the most minute difference in the mixing of paints. A motorist who has collided with a bicyclist but denies that the paint scraped along his wing is off the bicycle, may so be trapped. The two may be shown to be identical, not in coarse appearance, like colour, but in the finest details of chemical consistency. In one such case traces of the car type paint were found ingrained with a green bicycle paint on the bicycle frame, and green paint of the bicycle type on the car fender. How is it done? Well, an electric charge is passed through the test substance and it is made to glow with a kind of incandescence. This light is then split up by prisms into a spectrum which is photographed. Every metal or substance that can be mad

absolute fairness. The Crown is prosecuting the aims of justice, not hounding persons in the desire to pin crimes on individuals. and nothing short of convincing proof can be likely to convict a suspect in any English court of justice. The law, Dickens wrote, is "an ass", and it may sometimes appear to be, but it is a remarkably wise ass, given to stubborn demands for strict fairness How often it is said in criminal courts "It is important not only that justice shall be done, but that it shall also appear to be done." These minute traces of guilt must have absolute values which will sound reasonable and appear well reasoned and which will withstand searching examination by skilled defending counsel determined to test the soundness of the case for the prosecution on behalf of their clients. The public is the jury, as the jury comes from the public, and it is for them to judge the qualities of this scientific evidence.

One of the most remarkable of all scientific evidences of guilt is the fingerprint, and the study of this subject, dactylography, is a fascinating chapter in forensic science. Every individual is stamped before birth with indelible lines of individuality which remain with him for life. It is unfortunate for the criminal that the most detailed of all these lie on the ball of the finger—the very part of the rogue that he must use to break and enter premises, to manipulate locks and safe doors, to wield a weapon or to drag his victim away to a place of concealment.

The principal lines are set in the form of an arch, a loop or a whorl, or in some composite arrangement, and it is these major data which form the basis of the primary classification of fingerprints. Each individual line has a great deal of further detail. it may come to an end, fork or contra-fork, or loop like a tramline junction. Further, the ridge of each line is marked by little niches or interruptions owing to the emergence of the skin pores. So much detail may be included in a very small area that a single impression of one of the fingers left at the scene of a crime is infinitely more telling than the signature of the

criminal. Indeed, in the East, this method of signing trading bills and documents existed long before writing was sufficiently universal to enable signatures to be used for such a purpose. Galton, the famous anthropologist, estimated that the chances of two complete fingerprints being identical was as remote as 1 in 64 thousand million, some 30 times the world population. Superintendent Cherrill, Scotland Yard's fingerprint expert, has estimated that the chance is something like 1 in a septillion—that is a figure with no less than 42 zeros, many million times the world population. The figure, whatever it is, is so astronomical as to justify confidence in it as a proof of identity.

The print may be developed by iodine vapour or osmium tetroxide when the faintly greasy lines have been absorbed, say, on to paper, or photographed after dusting with a clinging powder of some contrasting colour.

Even the palm print has sufficed to convict a thief who broke into a shop in Shoreditch and rifled a safe, killing the old proprietor who stumbled into the shop to investigate the sounds of disturbance he had heard. Many a criminal has lost his chances of beating his way out of a mass of less convincing evidence piled up against him, because he inadvertently left this tell-tale evidence of association with the crime.

It is unfortunate that the skin itself is not a good surface for the detection and reproduction of these impressions, There is no telling whose hands strangled or pinned down the victim from the impressions the fingers leave.

Hair and blood have features of identity which are far less certain in their individuality Foreign hairs found on a suspect may be identical in colour, texture and form, with those of the victim with whom he has struggled, and *you might lightly assume this to* be good evidence to associate the two. But it is not, for there are thousands of brunettes and blondes—even artificial ones—and their hairs, varying slightly in shade, may resemble each other so closely as to be indistinguishable from each other.

A W.A.A.F. was found on her face in a ditch near her camp at Beccles, Suffolk, raped and suffocated in the mud. She had fought with her assailant and both blood and hair might have been expected on him. Suspicion fastened on a man serving in an adjoining R.A.F. camp—who was said to have been found at 5 a.m. the morning following the murder, washing his trousers and pressing them. There was a good deal of evidence pointing to his guilt and even one hair like that of the victim on his clothing would have carried great weight with the jury. There were three. Unfortunately, for the sake of scrupulous fairness, the police also took samples for comparison from the man's womenfolk at home as well as from the victim. The sample from his wife was quite indistinguishable from that taken at the post-mortem on the W.A.A.F., and the significance of those foreign hairs was nullified. Not only did the Crown decide that what might have been incriminating evidence could not be used: the Director of Public Prosecutions went further and placed the evidence in the hands of the defence. A conviction followed on the weight of the other evidence available.

Of course, in the majority of cases, foreign hairs found on victims of crime do carry their proper weight in the accumulated evidence against the accused, even though defending counsel obtain the admission that similar hairs need not necessarily have come from the same individual. The distinction between human and animal hairs is usually easy and never confuses the course of enquiry.

Blood is a most interesting laboratory study which has much the same weight in evidence as hair. There are too many people with similar blood groups to make the test individual.

The soldier who brutally clubbed a young girl to death in a rye field near Aldeburgh in 1944 walked out of the field with a vital clue caught in the foot of the trouser leg—a fragment of an ear of barley with a drop of blood splashed on it. The blood was of the same group as that of the

victim—and, fortunately, the suspect was of a different group.

Sometimes the wiping of a weapon may leave tell-tale shaped stains on cloth. A Canadian coloured soldier who stabbed a girl in a lane outside Guildford wiped the blade of the knife on his handkerchief and threw the weapon into the bushes by the road. It was found, and traces of blood of the same group as the stabbed girl's lay on its angulated blade. When the suspect was arrested he had, in his pocket, a handkerchief stained with blood clearly wiped on folds rather than splashed or soaked, and with one well defined line angulated just like that of the blade of the knife. Moreover, the blood group was that of the girl—not the suspect. An explanation he gave that he had cut his finger and mopped it with this handkerchief was palpably untrue.

Blood grouping has become more and more complex with the discovery of new specific agglutinable (clump-forming) substances. In addition to the four principal groups A, B, AB and O, A1 and A2 sub-groups, M, N, and P and the 'rhesus factor' have recently been added—increasing the chances of differentiating the blood of victim and suspect. The chances are greatest, of course, when B or AB, the rarer groups, are concerned, and the blood must be clean and not decomposed. Typing can be done even when the stain is quite dry and has been so for long periods, and as little, for instance, as that caught under the finger nail of a negro who murdered a taxi-driver in Essex might be enough to provide this telling evidence for the prosecution. Just as with hair, no one can ever say of blood that it belongs to anyone, only that it was of the same blood group and could have come from the victim (or assailant) whereas the tested group of the assailant (or victim) respectively is different. No jury is asked to credit this evidence with more significance than this. Some of the body fluids also contain the same substances and it may be possible to associate, or dissociate, individual

suspects with, say, cigarette ends or handkerchiefs which have been stained with saliva. These tests, like those on the blood, have their most telling value in eliminating suspects whose group proves to be different.

Let us see, now, how much evidence you might leave in breaking into premises and, though you had never intended it, using violence to quiet someone who unexpectedly disturbed you.

Suppose you crept at dead of night to the back of a pub where you and a "screwer" of yours had decided to "do a bust," turned the fastening catch of a small window and crept inside It was common talk in the bar where you had been getting some inside dope that the licensee, an elderly widow, usually took to bed with her the accumulated takings of the week: she might have as much as £300-£400 in her room at night and would be an easy victim. You crept upstairs in the dark, located the old lady's room and, after a short search, found the money in two bags in a dressing-table drawer, the lock of which you forced with a "stick". As you were going through the loot you heard your pal draw up outside in a car as arranged: everything seemed to be going all right, for the stuff was in your hands and there he was, ready with a "drag" to transport you both at speed through the night and deposit you both 80-90 miles away in a large city where you, your pal, the car and the money might become absorbed without comment.

You might think it was easy. But suppose one little thing were to miscarry—any little part of this intricate crime "set." Suppose, for instance, the old lady was awakened by the noise of your forcing her dressing table drawer. This was, in fact, precisely what happened in the case which is being used here to illustrate the complexity of even well-planned crime

The old lady sat up with a jerk, started to scream and, stumbling out of bed, endeavoured to reach the window to call for help. You struggled with her to stop her,

clapped a hand over her mouth, gripped her by the neck to silence her and fell with her to the ground. She was still screaming and you knelt over her tightening your grip to stifle her cries—when she suddenly went limp, dead. Suddenly your simple robbery had become, first robbery with violence, then, worse, robbery and murder: for killing —even if it were not intended—whilst committing a felony, would be murder.

You ran out to your pal and together you made your getaway without further incident, or so you thought But when the char came in the morning the hue and cry was soon started. The old lady bore the ineffaceable marks of strangling on her neck, of being pinned to the floor on her back and being violently asphyxiated by the tightening of a hand on the front of her neck The measurement of the steady cooling-off of the body—a routine the police officer will himself perform immediately he finds it—showed almost exactly when she had been murdered: the fixing of a time is of the greatest importance in narrowing the times for any alibi which a suspect may later attempt to establish.

Some smeared blood stains were noticed on the clothing and laboratory tests showed that these were human, but not of the same group as a sample of the victim's blood. Here was a specimen of the blood, in all probability, of the murderer

Two fingerprints were found on the sill of the window frame where entry had been made and these were at once photographed and classified Comparison showed they were not already on record, or the "wanted" notice would be all that was necessary to narrow the search to an individual. They were kept for comparison with those of any suspect.

Examination of the fingers showed a small head hair caught under the right forefinger nail. It was plainly human, and quite different from a specimen taken for comparison from the old lady. This, too, was added to the evidence of identity of the culprit, which was mounting.

The dressing-table drawers revealed scratches where the lock was forced, and the spectroscope revealed traces of several foreign metals scratched into the brass.

So the police had already a number of identity data which might enable them to point an accusing finger successfully at a suspect—when they had hold of him. And I haven't mentioned the routine enquiries they would have been making all this time. What strangers had been noticed about the bar in the last few days—anyone making enquiries about where the old lady kept her money or whether she slept alone? Had anyone heard or seen anything that night? In fact, a woman next door had. She had been awakened at exactly the time the police now knew the murder had been committed, by screams, and she had gone to the front window just in time to see a man run from the public house to a waiting car which was driven away up the London road. She had noted the number.

The number was circulated and a lock-up proprietor in London recognised it as having come in early on the morning following the murder. The plain clothes men waited and arrested the man who called for it next day: he gave away his confederate and this man's guilt was clinched as soon as the blood group, fingerprint, hair sample and a scraping from a small jemmy found at his lodgings, were examined. It might have been you—if you'd had the criminal urge to attempt such a tempting robbery.

The scales are heavily loaded against crime: your meagre wit and puny reserve, against the modern scientific intelligence and infinite resources of the most efficient police force the world knows. Crime may pay—once or twice—but not for long, and the patience and tenacity of the criminal investigation departments of the English police is, no doubt, one of the prime forces in the preservation of law and order. No country which claims a civilised order lacks crime, but none can afford to tolerate it, and the forces ranged against such disorders will always—must—outweigh them.

Noises from the Sun and Stars

BY GABRIELE RABEL

AMATEURS have made many important contributions to science, but perhaps in no other branch of knowledge has their co-operation been so essential and decisive as in the domain of wireless communication.

Amateurs scattered all over the earth were the first to discover the paradoxical fact that short wave transmissions are often heard on the opposite side of the earth while places close to the transmitter do not receive them at all—a discovery of far-reaching consequences

Amateurs again were the first to notice, during a period of sun-spot activity in 1936, a curious hiss on their short wave receivers which occurred only during day time and which appeared to be associated with the solar activity.

During the war, with highly sensitive receivers in operation and with improved direction-finding facilities, this remarkable phenomenon could be studied more accurately Reports came in from all sides

On February 27/28th, 1942, Army radar stations working on the 4·6 metre band heard strong noises similar to the random fluctuations of the receiver's internal noise but lasting continuously from morning to evening Never did the noise occur by night at any station.

The operators determined its bearings according to the normal practice for finding the direction of a source of interference—which, during the war, was naturally supposed to be an enemy aircraft The most striking results were obtained from two sites about 150 miles apart, which were able to follow the source of disturbance continuously in bearing and elevation. When the observers looked through the telescope attached to, and moving with the equipment they found they were looking directly at the sun. If it was

the enemy who jammed their reception, he seemed to be sitting on the sun and moving round with it.

Now, a certain amount of radiation and hence radio noise is to be expected from the sun, but we are told that the abnormal noise was "far in excess of the expected black body emission."

This phrase wants some explaining.

The Black Body

Every object is continually emitting energy in the form of heat and light and other radiations, and there is a definite ratio between the amount of energy emitted by a body and that which it absorbs from the surroundings. A silvered surface reflects more, absorbs less, and therefore also emits less radiation than a blackened surface.

A body which absorbs all the incident radiation and reflects none, is called a Black Body. Its energy emission is higher than that of any other body at the same temperature

As the temperature increases, the amount of radiated energy also increases, but not in equal measure for the various wave lengths The energy maximum shifts from longer to shorter waves (from "red heat" to "white heat"), and in the solar spectrum it lies in the yellow-green region. This energy distribution corresponds to that of a "black body" at 6000°C. That is not the temperature of the interior of the sun—which is estimated at 20-40 million degrees—but of that thin surface layer called the Photosphere which emits the yellow light. When astrophysicists speak of the "effective temperature" of the sun, they mean that of the photosphere.

The wave lengths of the visible spectrum, from red over yellow, green, blue to violet, lie between 700 and 350 millionths of a millimetre, and the radio waves, even those below ten metres which the wireless people are pleased to call ultra-short, are immensely long compared to those of light. At the given temperature of 6000°, the emission of

energy in these long waves is practically negligible, a minute portion of the internal receiver noise.

In periods of sun-spot activity, however, the situation is completely changed. On one day a noise was recorded which was equivalent to radiation 100,000-1,000,000 times that of the black body at 6000°.

During a recent period of strong solar activity, from January 30th to February 14th, 1946, Sir Edward Appleton took practically continuous records of the solar noise power flux on the 4 7 metre wave length, and he also studied those terrestrial and solar phenomena which are always associated with the solar noise, such as solar flares, magnetic storms, radio fade-outs and disturbances in the ionosphere. This is a region rather beyond the familiar and navigable portion of our atmosphere Through the action of various radiations the gas in this region is ionised, *i e*, split into electrically positive or negative particles. Normally the air is quite a reasonable insulator, but when ionised, it conducts electricity

When short radio waves reach these conducting strata, part of them is bent downwards and reaches the earth at a more or less considerable distance from the sender. This quasi-reflection of radio waves at the ionosphere affords a means to study the properties and fluctuations of that region.

Sir Edward Appleton, whom one might call the Master of the Ionosphere, distinguishes in it the following layers: the complex F-layer 250 kilometres (150 miles) above the earth (also called the Appleton layer), the E- or Heaviside layer at about 100 km , and further down the D layer which is little noticeable in normal times, but whose ionisation is considerably increased as long as a solar flare is visible This temporary increase in the D layer ionisation is the cause of two phenomena. (*a*) long radio waves are more than usually reflected at D, and (*b*) short radio waves which normally pass through D and are reflected at E or F, are heavily absorbed and do not reach the upper layers at all.

Therefore, during a fade-out on short waves, long wave signals are often enhanced.

The figures given for the altitudes of the ionospheric strata must not be taken too literally, because the altitudes vary with the time of the day and the year and other factors.

The Sun Spots

The puzzling configurations known as Sun Spots move across the solar disk in two belts extending from 5 to 40° latitude both north and south of the solar equator. They appear mostly in pairs and in each couple the leader and the follower in the journey around the sun have opposite magnetic polarity. If one is a north pole, the other is a south pole. If charged corpuscles revolve clockwise around one of them, they revolve anti-clockwise round the other. Further, if the leader is a north pole on the northern hemisphere, it is a south pole south of the equator.

It is a moot question whether the sun as a whole is, like the earth, a magnet If it is, its field would be between 10 and 55 gauss. But the field of a large sun-spot may amount to 4000 gauss.

Each individual spot appears spasmodically, remains visible for a few days or a few months, and then disappears. But when someone, as far back as 1843, thought of calculating the entire area covered by the spots, he found that from one maximum to the next there is a cycle of roughly eleven years.

Incidentally, *the sun does not rotate like a rigid body*, with all latitudes revolving equally fast. While the solar equator turns once in 24.5 days, the sun-spot zone takes about 26 days on the average.

At a time of minimum, the spots of a new cycle begin to appear in the higher latitudes of their appointed belts; as the cycle progresses, they gradually drift towards the equator, leader and follower keeping up their polarity. When they have arrived at about 8° latitude, they almost die out.

Now, according to a most interesting law discovered by G. E. Hale, of Mt. Wilson Observatory, the sun-spots of the new 11 year cycle, which begin to develop in the higher latitudes more than a year before the spots of the previous cycle have died away, are of opposite magnetic polarity. If the leader was first a N. pole, it is now a S. pole Owing to this polarity reversal, the "magnetic cycle" lasts about 23 years.

Recent Observations (Sun Spot Period of 30th January to 14th February, 1946)

The noise was high during the whole passage of the large spot across the solar disk, it was highest on 5th February, when the spot reached the central meridian, and again on 8th February. On the 4.7 metre band, the noise was *10,000* times, and occasionally even *100,000* times louder than the normal receiver noise. The maximum area covered 0 005 of the solar hemisphere, against 0.002 in 1942.

A large magnetic storm began on 7th February, at a time when the large sun-spot was 1.9 days—or 25 degrees—past the central meridian. The storm lasted for about thirty hours. It was accompanied by a display of the northern lights. The horizontal intensity of the earth's field went up so violently that the compass needle deviated by two degrees.

In the critical period ten radio fade-outs were recorded, and the simultaneity between major fade-outs and marked increase in the solar noise was striking

A further magnetic disturbance occurred on 13th February. Some observers noticed solar noise a few minutes before sunrise and after sunset. And one observation seemed to indicate that similar noises also came from the direction of the magnetic north pole (approximately 78° N, 69° W.).

When after a half rotation of the sun the spots appeared again, they were smaller, and so was the noise they produced.

Little abnormal noise is heard on wave lengths smaller than one metre. It becomes significant at 1.5 m, and its

magnitude rises steeply as the wave length increases to five metres Outside the reflections and absorptions of the ionosphere the spectrum may differ.

Sir Edward Appleton considers it as established that the source which is responsible for the increase in ionisation and for the solar noise, consists in electromagnetic radiation which has its origin in the active parts of the sun and travels to the earth with the velocity of light (186,000 miles per second) together with the visible radiations

At the same time it seems that a cloud of charged particles moving towards the earth is responsible for the magnetic storms. This assumption was first made at Mt. Wilson and now confirmed at Cambridge Observatory. Spectroscopic observations made during the February storm appeared to show that the cloud moved towards the earth with a velocity of 750 km (450 miles) per second. This explains why the magnetic storm began almost two days later than the electromagnetic disturbances.

Not only is our own good old sun sending wireless messages to us, messages are coming in from far more distant regions.

In 1933, Jansky, an engineer of the Bell Telephone Co. in New York reported in *Nature* that high frequency atmospherics which he had at first ascribed to the sun, could not possibly have their origin there He was led to infer that "the source of these disturbances remains fixed in space . . . located in some region that is stationary with respect to the stars "

The assumption that the far-away stars interfered with our radio sets was—as is usual with new discoveries—treated with scorn. But to-day it is an accepted fact that "atmospherics" are produced also by a radiation which comes to us direct from the centre of the Galaxy.

And after all—why not? Have not radiations from the Galaxy long since been recorded by our eyes and photographic plates?

Some newspapers at the time reported that physicists had

succeeded in getting *echoes* from the sun and stars. These reports were based on a misunderstanding of the related facts. So far our communication with the universe is one-sided.

Postscript

Since this article was written, it was possible, by application of a method introduced by Michelsen for determining stellar diameters, to establish that the diameter of the source of abnormal noise is of the same order of magnitude as the visual sun-spot.

Chemical Front

Comment

In the last twenty years chemistry has changed its whole focus of interest. The atomic theory in this sphere has been completely worked out, the different kinds of binding by which atoms are held in molecules is understood, the ways in which molecules react one with another largely probed. The chemistry of ores and minerals and of drugs, dyes and coal tar products has long been explored, and present-day chemical industry is based on applications of facts and ideas known for the most part since 1914. When new drugs like the sulphonamides or D D T. are developed, their chemical properties have been reported for thirty years or so, and it is their biological effects which are the true modern discoveries. The chemistry taught in schools is still the old mineral and coal tar chemistry, but interest in chemical research has shifted to an entirely different field, taking its old knowledge and old methods with it, yet often having to invent new methods and new concepts

The new field is that of biology. The organic chemist has begun a large-scale attack on the chemical nature of the substances which are produced by, or which make up, living matter. The nature of all the vitamins in food, the forms in which these molecules are found combined in living muscle or brain, their eventual fate in the urine; the composition of hormones produced by ductless glands, which make an individual male or female, giant or dwarf, which make roots and leaves and flowers grow; the composition of all the different natural plant and animal starches, and fats, and proteins which compose the bulk of protoplasm; the molecular structure of the nucleic acids which seem to be the essential chemical components of chromosomes and the genes of heredity on the one hand; and of

infectious viruses of diseases such as mumps, 'flu and measles on the other; the field is vast and as yet barely entered. The problems of chemical analysis alone can be appreciated by comparing the size of molecules treated by the old chemistry with the size of those facing the new. A molecule of D.D.T., for instance, contains about 30 atoms linked together, and has a molecular weight in the neighbourhood of 300 (*i.e.*, one molecule is three hundred times heavier than an atom of hydrogen). A molecule of insulin, on the other hand, a fairly typical protein, has a molecular weight of about 40,000, over a hundred times greater than D.D.T., and proportionately more atoms per molecule. It is the task of chemistry to place all these different atoms in relation to one another in the molecule, and to explain the chemistry and biological effect of insulin purely in terms of these relations. It is a task not yet half completed.

Two points come out of the recognition of this revolution of chemical interest. One is practical; has the time not come for the chemistry taught in schools to be radically revised, in senior forms at least? Examination syllabuses which insist on the teaching of inorganic chemistry in great detail, with a smattering of coal tar chemistry thrown in, are preparing pupils for a world and a chemical industry which is rapidly fading away. Many of the same fundamental chemical ideas now taught could be equally well or better taught by examples from biological chemistry, with much more relevance to present-day life and needs. The chemistry of vitamin C is not more complex than that of aniline, it is merely less widely known because more recently discovered.

The second point is of wider interest. It is a contribution to the debate whether knowledge is infinite, or whether a time will come when man knows all there is to be known. The old chemistry seemed to be approaching this latter state, a state of complete knowledge; and there were those who saw the same thing happening in other sciences and

said, "In two hundred (or five hundred) years' time science will be worked out, and men will have to find other intellectual pastimes." Yet chemistry continues, with as wide a field of ignorance before it as ever. It has done this by changing its artificial boundaries. Chemists have chosen a new viewpoint with fresh questions to be answered, and fresh boundaries different from the old And this is the answer to the primary problem The human departments of learning are finite, limited, based on a particular century's interests. But the centuries pass, the interests change, the boundaries are altered, and the Universe remains vast and mysterious, and for the greater part in total darkness

Silicones

Plastics represent a modern link between the old and the new chemistry. They are composed of enormous molecules, often modelled on natural hair or cotton, but they involve the facts of classical chemistry in their production. Polymerisation, the ability of small molecules, all alike, to combine together in vast atomic assemblages with new properties not unlike some of those of the molecules of living matter, has been known for a long time, but only intensively studied in the last twenty years It has been thought of quite largely as the peculiar ability of carbon atoms to link together in long chains, and the changes are still being rung on this theme, with the production of new varieties of plastic. One of the more recent is the use of fluorohydrocarbons—carbon atoms with fluorine atoms attached Fluorine is a close relative of chlorine, and compounds of both elements with carbon are practically important

CH_4 methane (marsh gas)
$CHCl_3$ chloroform (anaesthetic)
CCl_4 carbon tetrachloride (solvent)
CCl_2F_2 propellant in insecticide bombs
$F_2C = CF_2$ tetrafluorethylene

Polymerisation of tetrafluorethylene to give a chain thus

$$\begin{array}{ccccccc} & F & & F & & F & \\ - & C & - & C & - & C & - \\ & F & & F & & F & \end{array}$$

yields heat-resistant, chemically *inert solids, which can be moulded into any* desired shape

But the end of 1944 saw the announcement of polymers involving another old principle altogether Silica, or quartz, known as the basis of all glass and in impure form as ordinary sand, is the oxide of the metal silicon, which is sometimes alloyed in steel It has been known for a very long time that silicon has a chemistry not unlike that of carbon, and differing from most other elements in that it forms compounds where silicon atoms combine together in chains; but this knowledge has usually been relegated to obscure footnotes in the older books. However, American chemists have developed it into a new class of plastics, the siloxanes or silicones, a typical example being the dimethyl siloxane polymer

$$\begin{array}{ccccccc} & CH_3 & & & CH_3 & & \\ & | & & & | & & \\ CH_3 - & Si & - O - & & Si & - O - & \\ & | & & & | & & \\ & CH_3 & & & CH_3 & & \end{array}$$

a long chain of alternating silicon and oxygen atoms, with CH_3 groups at the sides.

Such a plastic is liquid at ordinary temperatures but does not mix with water or any other solvent. It does not conduct electricity, and consequently finds a valuable practical use for electrical insulation. A thin film of the silicone is very resistant to water, the great enemy of insulation, is very resistant to oxidation, is unaffected by heat (it remains viscous over the temperature range—40° C. to 200° C. with remarkably small change), is chemically *inert and adheres tenaciously to a glassy surface.* By altering the groups of atoms attached to the silicon "backbone" other members of the silicone class are obtained.

B.A.L.

These letters stand for a wartime discovery made at Oxford, British Anti-Lewisite, a new drug with valuable peace-time uses. The problem Prof. R. A. Peters and his colleagues were attacking was protection against poison gases, in particular the arsenical smokes such as lewisite. They saw the problem as a twofold one. On the one hand, what did the lewisite do in the human body which made it so poisonous, and on the other, what possibilities were there of neutralising lewisite itself once it got inside? Before the war they had been interested particularly in the function of vitamin B_1, and had shown that together with a specific protein present in the brain, and elsewhere, it formed an enzyme in the living cells which played a vital part in the usage of sugar by the brain. The sugar is broken down in a series of small steps, each yielding energy for living processes, and these breakdowns take place only if the right enzyme is present: if it is missing, as in vitamin deficiency it will be, sugar breakdown comes to a halt, the living cells run out of energy and cease to function, and disease appears. The particular enzyme, containing B_1, was called pyruvic oxidase, sometimes decarboxylase, since it worked the chemical change from pyruvic acid to acetic acid, with the help of oxygen from the air.

$$CH_3 - CO\,COOH + O \rightarrow CH_3\,COOH + CO_2$$

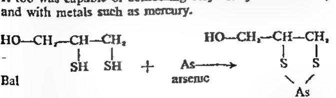
The Oxford workers showed that the protein part of the enzyme contained sulphur atoms, apparently essential for its activity. Normally the sulphur atoms had hydrogens attached to them—SH, but if the H was replaced by silver or mercury, or arsenic, the enzyme could no longer convert pyruvic to acetic, although plenty of vitamin were present, and again the living cells ran out of energy, and illness came. Thus both vitamin and protein are necessary for the chemical change

Early in the war, then, it was shown that lewisite combined with the sulphur atoms in pyruvic oxidase in brain,

and with sulphur in other enzymes, and stopped their activity. This was quite enough to explain the poisonous activity of lewisite—but how to stop it? The first thought was to give other, much simpler, compounds containing —SH, such as cysteine and glutathione, each molecule of which contains a sulphur atom of this sort. But it was found that, though lewisite would combine with cysteine, it preferred to combine with pyruvic oxidase if given the choice. Consequently doses of cysteine would not protect an animal from the effects of lewisite.

At this point one of the Oxford scientists remembered that when poisoners kill their victims with arsenic, the arsenic accumulates chiefly in the hair and nails and skin, which are known to contain a great many sulphur atoms in their protein (keratin). He thought it would be worth while to find out how strongly the arsenic is held in the hair, and how it is done. He found that the arsenic was very firmly held indeed, and closer investigation showed why this was. Each arsenic atom was held not by one sulphur atom, as was the case in cysteine and in pyruvic oxidase, but by two sulphur atoms at once, the two sulphur atoms existing very close together so that they could share the arsenic.

Accordingly a simple chemical was synthesised in which the same situation occurred: two sulphur atoms side by side. This compound, chemically 2.3 dimercapto-propanol and a relation of ordinary alcohol, was called Bal for short. It too was capable of combining very firmly with arsenic, and with metals such as mercury.



Bal

Ways of giving it into human veins, as well as washing eyes with it and so on, were worked out, and it was found

to give complete protection. Taken after exposure to lewisite, or poisoning by arsenic or mercury, it circulated in the blood, snatching up the arsenic or mercury atoms before they could harm the pyruvic oxidase or other enzymes. Later it was excreted in the urine, carrying the poison with it. Chemists, working for war purposes, have presented doctors with another valuable drug.

Chromatography

One of the important practical problems in chemistry is the purification of individual substances. The products of a chemical reaction, and still more the great mixture of substances obtained in extracts of living tissues, must be made to yield up their components one by one: each substance singled out, and preferably crystallised, can then be analysed and studied and its molecular structure and chemical behaviour defined. Recently, new and powerful methods have been developed for these separations and purifications. They depend on two older discoveries: adsorption, and partition between solvents.

Charcoal, various natural earths, such as fuller's earth, and other siliceous and diatomaceous soils, and alumina (aluminium oxide) have the power to extract substances from their solutions, and to hold on to them in spite of washing. This hold is physical not chemical. For instance, if a substance has been adsorbed by alumina from an acid solution, the alumina may subsequently be made to give the substance up again into solution by washing with alkali or alcohol. Now substances vary very greatly in their ability to be adsorbed under a particular set of conditions, and so substance A may be much more strongly adsorbed than substances B, C, D—also present in the same solution. A simple step to purify A therefore consists in adding adsorbent (*e g*, fuller's earth) to the solution, stirring it about (for it does not dissolve), and then withdrawing it again by filtration or some other method. When withdrawn it carries substance A out of the solution with it, and thus

A is largely separated from its chemical fellows—provided the latter are adsorbed very much less

If the differences in adsorption are not very great, simple addition and removal of the adsorbent effects no useful change.

Another more sensitive technique exists for such cases: chromatography The adsorbent is packed into a vertical tube, and the solution poured on the top and slowly sucked through the column of adsorbent. The most strongly adsorbed substance never gets far down the column, but adheres to the top of the adsorbent, occupying its whole surface, and forcing less strongly held substances to move further down the column where there is more space The result is that a series of bands appear in the column (see plate 5) each representing a distinct chemical substance. By changing the character of the fluid put on the top (as by changing its acidity, or adding a different solvent) the strength with which the adsorbent holds its substances is loosened to different characteristic extents, and the bands move down the column at different rates with ever-widening spaces between them. Finally the purified substances issue one by one at the bottom of the tube and can be collected.

Chromatography is thus a simple and sensitive way of determining how many different substances are present in a mixture and of separating them one by one, providing they are coloured so as to show up in the column. If they are colourless some special test for their presence on the column or in the fluid coming out at the bottom must be used, and this is a severe limitation The other limitation to the method is that as often as not there may be no known adsorbent for the chemical it is desired to separate, and therefore adsorption methods and chromatography can do no more than remove a few of the impurities.

However, in the last six years or so, A J. P Martin and R. L. M. Synge of the Lister Institute, London, have developed a new and different type of chromatography, not subject to these particular limitations, since it depends not

on adsorption but on partition between non-mixing solvents. Very often a chemical is soluble in more than one solvent, for instance in butyl alcohol and chloroform as well as water, but dissolves in each solvent to a different extent at room temperature If therefore we have a bottle containing both chloroform and water, which do not mix but form two distinct colourless layers, one on top of the other, and add substance X to the bottle, some of X will dissolve in one layer, some in the other, and the partition of X between the two solvents will be quite characteristic of X. A different substance Y will have quite a different characteristic partition between the same pair of solvents

If the partitions of X and Y are very different it will be possible to separate them merely by extracting their solution in water with chloroform, for X will pass much more completely into the chloroform than Y. But if their partition coefficients are not distinctly different, as is often the case, such a simple technique is no good. What Synge does therefore is make the two solvents meet in a vertical tube. he fills the tube with a jelly of silica (from waterglass) which contains a great deal of bound water, and pours a solution of X and Y (or whatever the mixture may be) in another solvent such as chloroform or butyl alcohol on the top, and sucks it through. As the solution passes downwards it exchanges its dissolved substances with the water, those chemicals most strongly attracted into water staying at the top of the column, while the more equally partitioned appear lower down. Again, therefore, a series of bands appear on the column, and can be made to move down and collect separately by changing the composition of the solvent. If the substances themselves are colourless they are very likely acidic or alkaline, and if a little indicator like litmus is incorporated into the silica jelly, each substance on the column will mark its presence by changing the colour of the indicator.

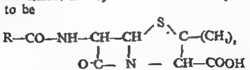
This partition chromatography has already been applied

with great success to the analysis of mixtures of amino-acids, the building bricks of proteins and the components of peptides like the antibiotic Gramicidin, to mixtures of fatty acids, and to mixtures of sugars, and is going to prove an important analytical and preparative tool in the whole of biological chemistry.

A modification is also of value in medicine. Instead of using a silica jelly, moist paper can be the basis for the chromatogram. Under standard conditions, with paper of known dimensions and so forth, each amino-acid comes after a given time to occupy a definite characteristic point on the paper. Since it requires very little of each chemical to be visible on the paper, this becomes a very sensitive analytical method. A little blood or urine, for instance, will yield its traces of amino-acids up to the characteristic points on the paper, and by seeing which areas are occupied and which vacant, it is possible to note down exactly which amino-acids and peptides are present in the starting material (see plate 6).

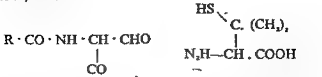
Synthetic Penicillin

Chromatography has played a part in the production of pure penicillin from the growth of mould which makes it. Partition chromatography is also proving valuable in working out the way to make penicillin in the laboratory and the chemical factory. The formula of penicillin is known to be



where R on the extreme left stands for a number of possible different groups of atoms. In penicillin G it is a benzyl group ($C_6H_5CH_2$), in penicillin X, p-hydroxybenzyl, in penicillin K, n-heptyl—for there are a number of naturally occurring penicillins, with somewhat different medical effectiveness. The formula, at first sight very fearsome,

splits into two parts in the laboratory by breaking three bonds, thus



oxazolone fragment penicillamine fragment

The synthesis of penicillin G starts with a benzyl oxazolone and with penicillamine, and attempts to recombine them.

Work of this kind has been going on since 1944 in both Britain and America, with very poor success. No pure chemical substance could be isolated, and the reaction mixture at the end of the experiment, when tested on bacteria, had an activity of only 3.6 units per milligramme of solid as against 1667 units for pure penicillin G. It seemed doubtful in fact whether any penicillin was being formed, the activity was so low. What activity there was might be due to some other substance, perhaps quite unrelated

It was decided therefore to compare the properties of the unknown synthetic substance with standard penicillin. Bacteria vary in their sensitivity to penicillin, and they were found to vary in exactly the same way in sensitivity towards the unknown substance. Some bacteria produce an enzyme, penicillinase, which destroys penicillin, and also abolishes activity in the synthesised solution. Rabbits given penicillin excrete a certain characteristic proportion in their urine. When given the unknown instead, the amount of activity appearing in the urine was that expected after a dose of penicillin.

But the most convincing argument that penicillin really was being synthesised in minute amount came from a chemical experiment using modern atomic physics. Penicillamine, containing radio-active sulphur instead of normal

sulphur, was prepared and used in the synthetic reaction. The unknown penicillin-like substance formed now had a measurable amount of radioactivity due to its combined sulphur. Some natural crystalline penicillin was now thrown in and recrystallised from the solution. The crystals were separated off, and found to have become radio-active. They were recrystallised and recrystallised a number of times, but their radioactivity remained constant in amount. Crystallisation is a way of getting a pure substance, free of impurities. The fact that the radio-activity remained constant in spite of continued recrystallisation argued that the radioactive sulphur was actually present in penicillin molecules chemically indistinguishable from the natural ones thrown in, and therefore all crystallising together. This was therefore a very strong argument that a little real penicillin was being synthesised in the laboratory.

The research workers persevered. By means of partition chromatography they increased the activity of the synthetic substance to 44 units per mgm. Penicillin has a characteristic "colour" in the infra-red part of the spectrum, and it was now possible to make this out in the synthetic preparation too—a further sign that research was on promising lines. By modifying the synthesis a little, Professor Vincent du Vigneaud of Cornell University, New York, has now been able to get a yield of 0.1% of the expected penicillin G, and is studying the reaction further to improve the situation. Synthetic penicillin is still a very long way from factory production, but that it will come in time there is no doubt. Prof. du Vigneaud points out that it will be possible to try the synthesis with other sulphur compounds than penicillamine, and that this may open a whole new range of drugs, some of which may be better even than penicillin for some purposes.

De-Icing of Ships

BY G. VAN PRAAGH

ATTEMPTS to reduce the menace of ice are of two kinds: in the first place, certain measures can be taken to reduce the likelihood of icing, and these include the fitting of steam pipes just below deck and inside the superstructure, and secondly, means can be provided to facilitate the removal of the ice once it has formed. The measures adopted on aircraft are not, in general, applicable to ships. These include the use of pulsating rubber surfaces on the leading edges of the wings, and the use of a continuous spray of fluid over windscreens, etc, to lower the freezing point of water and prevent the formation of ice. After much experience on aircraft in service, the use of heating devices was found to be the most effective remedy. On ships, attempts to melt the ice by buckets of hot water or by steam jets are only partially effective, because a great deal of heat is needed to melt a little ice. Further, if the temperature is still below freezing point when the operation is being carried out, the melted ice may freeze again unless it can be pushed overboard first. Mechanical detachment of the ice is no easy matter, for ice adheres most tenaciously to clean, grease-free surfaces and a ship has often been thoroughly de-greased by wind-swept rain and spray before it becomes iced-up.

During the war, owing to danger from enemy attack, convoys were forced to take more northerly routes and, under certain weather conditions, accumulation of ice on ships became a serious menace. In order to avoid heavy air attacks from Northern Norway, the Murmansk convoys had to leave the comparatively calm and warm weather which is maintained by that arm of the Gulf Stream which passes round North Cape and keeps Murmansk unfrozen

throughout the winter, and enter the colder and more stormy regions of the Arctic, where bitter winds coming from northerly directions and often veering rapidly, are encountered. In these regions the temperature of the water may be about 29°F and the air temperature anything down to 0°F. The superstructure of the ship therefore gets very cold, and any spray blown over it freezes immediately. When this occurs, particularly with a headwind, ice may build up at rates as high as 1½ inches an hour. If the wind is on the beam, the ice will be formed on that side of the ship and thus cause a list, which may become serious. Maximum icing thus takes place in bad weather, so that the difficulties for the crew engaged in de-icing are greatly increased by the ship's motion as well as the extreme cold.

The very rapid rate of cooling of the ship by the wind makes the prevention of the building up of ice almost impossible. As stated above, ice adheres to clean metal or paint with great tenacity and it seldom breaks off cleanly. The force required to shear ice off a clean steel surface is of the order of one ton per sq. ft., but a thin film of suitable oil or grease reduces this by at least 90 per cent and the ice parts cleanly. However, any kind of de-icing dressing which has to be applied to ships' surfaces to facilitate removal of ice must be able to withstand heavy weathering at moderate temperatures for several days in addition to remaining soft at low temperatures.

The whole problem of the fitting of ships for Arctic service is too large to be dealt with here, but all officers who experience icing trouble agree that any device, however small or simple, which makes the task of removing the ice easier, is valuable. The use of improved tools for de-icing was one step taken to make this task less arduous. Ice axes or mattocks are too heavy, for if wielded with one hand (which is necessary under icing conditions, as the other hand is needed for holding on), they exhaust a man in about 10 minutes. Most of the energy is expended in shattering the ice instead of breaking it up cleanly. Ice spikes, such

as are used by fishmongers and ice merchants, mounted on wooden handles of various lengths, are much more efficient tools for cleaving the ice. Another problem that arises is the protection of canvas and rope. The latter presents special difficulties, for although the fibres can be waterproofed, and thus prevented from freezing individually, it is impossible to exclude water from the interstices of the rope which in consequence sets hard on freezing.

Development of De-icing Materials

De-icing dressings for application to certain parts of a ship's superstructure in order to reduce the adhesion of ice were developed as an emergency measure during 1942. The work was done by a small research team working in a University laboratory under Dr. A. S. C. Lawrence. De-icing materials must pass two tests: (1) a weathering test; (2) an ice-detachment test. The materials were required to withstand a gale of 90 m.p.h. carrying water in the form of drops up to a quarter of an inch in diameter, and to facilitate the removal of ice down to —20°C. Two materials were developed, one which could be easily painted or sprayed on to large flat surfaces, and another which could be applied like putty around coarse mechanisms (such as handles on ammunition locker doors, depth charge release gear, moving parts of derricks on merchant ships, etc.), to prevent the keying-in of ice with the consequent locking of the mechanism.

For the development of these materials two pieces of apparatus were built. The first was a gale tunnel for the weathering test, and the second a device for freezing ice on to a treated metal surface and measuring the force necessary to detach it. The gale tunnel, illustrated in Plate 3, consisted of a glass tube about four feet long and three inches in diameter connected at one end to a cast-iron box into which air was blown from a rotary blower driven by a one horse-power motor, and into which a jet of water, in the direction of the air-stream, also entered. The

water was picked up by the moving air and assumed the velocity of the air by the time the exit of the tunnel was reached. The specimens to be tested were placed at right-angles to the tunnel and received the direct or oblique impact of the gale, whose speed could be varied from 20 to 150 m.p h. Steel plates were covered with the various materials and tested in the gale for periods varying from minutes to hours. The other piece of apparatus, illustrated in Plate 4, consisted simply of a steel plate on which the de-icing material was placed and on to which a small block of ice was frozen The apparatus was set up inside a thermostatically controlled refrigerator and the forces necessary to remove the ice were measured directly at temperatures from —5° to —30°C.

The first material developed was based on petroleum jelly. This substance alone is too stiff to paint on and, owing to the crystallisation of paraffin wax, too hard at low temperatures to be suitable as a de-icing paste. It was therefore mixed with low freezing-point oil so as to produce a mixture of suitable consistency, *i.e.* one which was not removed by the weathering test and which reduced the ice detachment force below a specified value This mixture was still too stiff to paint on easily and was therefore diluted with volatile spirit. The resulting material as applied is too fluid to withstand the weathering test, but the spirit evaporates in an hour or so after application, leaving a thin film with suitable de-icing properties Films of various thicknesses were tested, and it was found that the least thickness required for the dressing to be effective was well below the thickness of the film left when the material is brushed on in the ordinary way.

The second material developed was a putty-like substance, and was made from a grease stiffened to withstand weathering by the inclusion of a solid filler. This procedure was adopted because the solid, while enhancing the weathering properties of the grease, has no temperature coefficient of consistency, so that the only stiffening at low temperatures

is that due to the oil base of the grease. Fibrous asbestos was chosen as a suitable filler. In making up such a mixture the changes could therefore be rung on several variables. the percentage of asbestos, the proportion of soap to oil in the grease, the nature and viscosity of the oil base and the type of soap. About two hundred experimental mixes were made up and tested. Statistical representations of the results revealed an unexpected condition, namely, that no mix which was made from grease based on an oil of less than a certain viscosity could meet both the weathering and ice-detachment requirements. It was also clear that the asbestos and soap content could be varied only within narrow limits The final composition consisted of 32 per cent asbestos in a grease containing 23 per cent of lime soap in an oil of a certain viscosity.

Large Scale Tests

Large-scale de-icing tests were then carried out in one of the cold chambers of the *Eldorado Icecream* Company. Surrounded by crates of strawberries, raspberries and blackcurrants, the experimenters sprayed iron sheets with water from a stirrup pump, periodically having to leave the cold chamber (—20°C.) to thaw out the pump and recover their breath. Sea trials of materials were then made on a destroyer on the Murmansk route One of the trials not anticipated (at any rate by the scientist on board) was the attempted attack by the Scharnhorst. Very heavy weather was encountered and the de-icing materials stood up well.

Acknowledgment is due to the Admiralty for permission to use material from an article by the author in the *Journal of the Royal Naval Scientific Service.*

Oceanography

BY DR. G. E. R. DEACON, F.R.S.

1. *Introduction*

DEEP-SEA exploration has commanded the attention of civilized nations since the earliest times, and the foundations of oceanography can be traced to observations of tides and currents, and occasional notes on marine animals and plants, made during the early voyages. It was not till science as a whole developed rapidly in the 18th and 19th centuries that systematic investigation became possible; and only in the past 100 years has it been possible to build up the organized body of information which now justifies the recognition of oceanography as a distinct branch of science. In its most modern conception it embraces the applications of all other sciences to the study of the sea.

To approach the subject in a rational way requires first a study of the shape and composition of the ocean basins; this is followed by an investigation of the physical and chemical characteristics and movements of the water and of the interaction between the atmosphere and the oceans, and completed by a detailed study of the nature, abundance and activities of the marine plants and animals. Many expeditions and laboratories have studied all these aspects and others have concentrated on either the physical or biological problems. It is almost impossible to study one branch without paying some attention to the others, and it is largely by such collaborative work that the subject has grown.

2. *Submarine Geology*

The marine geologist is concerned mainly with the topography of the ocean floors, the nature of the sediments and the rocks below the ocean floors.

Topography

There seems to be no record of successful deep-sea soundings till the later part of the 18th century, and in H.M.S Challenger, 100 years later, a sounding, made by lowering a heavy weight on a hemp line as thick as a finger, still took several hours. An American midshipman had devised a more handy method, using thin twine and a weight which detached itself on striking the bottom; and it was not long before the introduction of thin steel wire brought further improvement Using such apparatus in 1874 a U.S survey ship took only 2½ hours to make a sounding in water 5 miles deep, all the winding being done by hand.

In spite of the increasing importance of deep-sea sounding as more telegraph cables were laid, and the use of steam winding engines which made the operation much easier, the number of deep-sea soundings increased slowly. The first depth chart of the North Atlantic Ocean, published in 1854, was based on about 150 deep soundings, and the total number of deep soundings in all the oceans in 1914 was only about 6,000.

The 1914-18 war accelerated the development of a new method, that of echo-sounding, by which the depth is calculated from the time taken by a sound pulse to travel to the sea bottom and back. With this method soundings can be obtained without stopping the ship, and a research vessel may now make hundreds or thousands of soundings where she would have made one, but there are still areas with very few soundings, especially in the Indian and South Pacific Oceans.

Where detailed soundings have been made they have revealed new problems. Some submarine elevations have been shown to be as rugged as any mountain landscape; and although it has long been known that many river channels, notably those of the Congo and the Indus, are continued under the sea as steep-walled submarine canyons, cutting across the continental platform into oceanic depths,

the new soundings have revealed so many other canyons as to make their origin the subject of animated enquiry. Many of those discovered off the U.S. Atlantic coast appear to have no obvious connection with the present rivers on land.

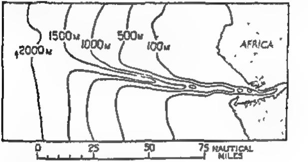


Fig 2—Depth contours in metres showing the submarine canyon off the mouth of the River Congo.

Comparatively little of the ocean has been sounded with the accuracy desired by the submarine geologist. The problem of knowing the position of the ship with sufficient accuracy while she makes the sounding, has to some extent replaced the early difficulty of obtaining an accurate measurement of depth; and the new systems of radio-navigation will facilitate detailed sounding by accurately locating her position.

Sediments

The rate at which sediments are deposited on the bottom of the deep ocean varies from a fraction of a centimetre in 1,000 years far away from land, to perhaps 10 centimetres in 1,000 years near a continent; the topography of the bottom is known to have some effect, and ridges and banks tend to be swept clear, while depressions offer conditions favourable for deposition The very small rate of growth of the sediment is due to the bottom layer being a zone of

CAPTIONS FOR PHOTOGRAVURE INSET

Plates 1 to 9

Plate 1. Waves in a mid-Atlantic storm.

Plate 2. Swell from a mid-Atlantic storm arriving at the Admiralty wave and swell recording station at Perranporth.

Plate 3. Gale Tunnel (see page 73)

Plate 4. Direct measurement of ice detachment force; a weight has been added to the pan hanging from the rectangular block, which is frozen to a board, in an attempt to detach the block.

Plate 5. Chromatography on alumina: analysis of three different mixtures showing separation into different coloured bands as solution moves downwards (see page 67). Reading from above down: on the left bands of Iron, Lead, Silver; on the right Iron, Copper, Cobalt; in the middle a complex mixture.

Plate 6. "Two-dimensional" partition chromatogram on paper. Each blob is an accumulation of one amino-acid separated out from the mixture of many; swept from left to right by one solvent, and downwards by another so as to come to occupy a characteristic place on the paper, permitting identification (see page 69).

Plate 7. Comparison in same microscopical field of orange fibre A, found in nail scraping of girl raped and murdered and sample fibre B of same colour from accused's shirt.

Plate 8. Human head hair on blunt weapon found discarded in bushes near scene of murder. Hair suitable for comparison with sample from victim.

Plate 9. Luton sack murder. Comparison of finger prints of dead woman and those on pickle jar found in house of supposed victim.

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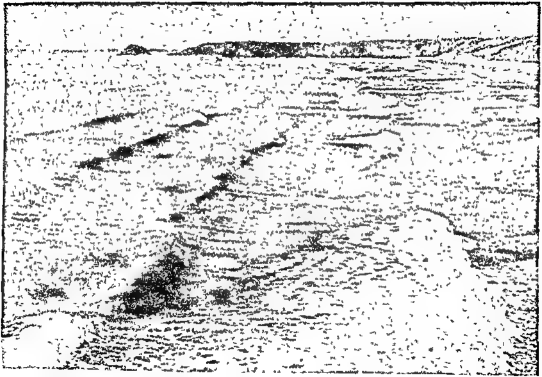
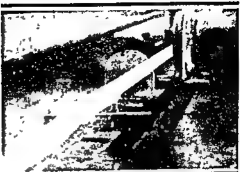
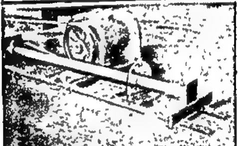




GALE AT 150 m.p.h.



TEST IN PROGRESS

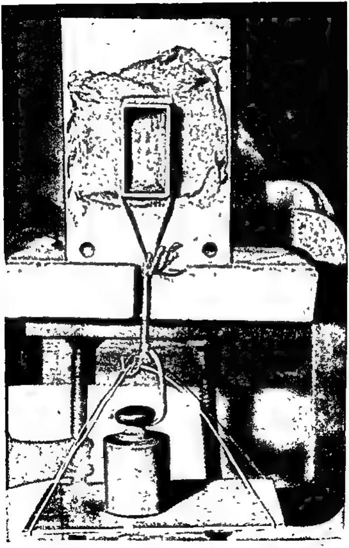


Plate 4 : See De-Icing of Ships, page 75

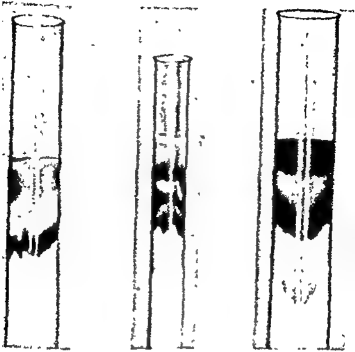


Plate 5 This and Plate 6 are discussed in Chemical Front, page 66.

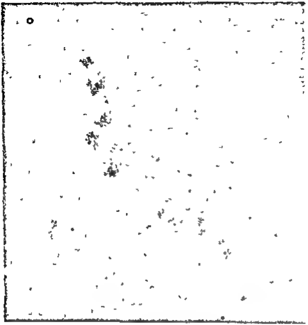


Plate 6

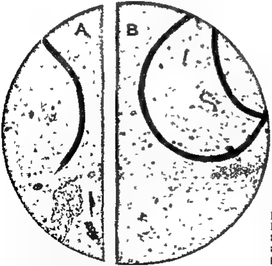


Plate 7 This and Plates 8 and 9 refer to article on Science and Crime detection, page 36.

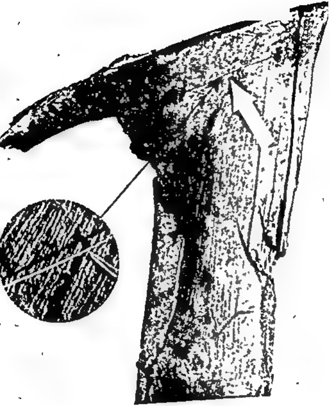
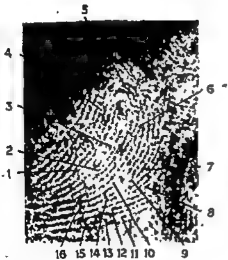


Plate 8

Plate 9.

PHOTOGRAPHIC ENLARGEMENT OF THUMB MARK ON PICKLE BOTTLE



PHOTOGRAPHIC ENLARGEMENT OF LEFT THUMB IMPRESSION ON FINGER PRINT FORM

active decomposition of the detrital material which descends from above, the organic and inorganic products being carried away in solution by the water movements

The sediments belong to two main groups, being either the skeletal structures of marine animals and plants, or inorganic material brought into the ocean by rivers, winds or volcanic activity The nature of the skeletal structures depends largely on the climate and the physical and chemical characteristics of the water above the area, the Antarctic climate and the abundance of nutrient salts in the Antarctic surface water favour the deposition of siliceous skeletons, while the sediments below the warmer and less productive surface waters farther north are mainly chalky In the greatest oceanic depths the deposits are chiefly inorganic, and called Red Clay, though the detailed character and colour depend to some extent on the geology and climate of the neighbouring land masses Information about the stratification of sediments, obtained by driving a collecting tube into the bottom, is used as evidence of climatic changes and movements of the sea bed in previous ages

3. *Physical and Chemical Problems*

The physical properties of the water depend primarily on its temperature and salinity, but such processes as the conduction of heat, transfer of energy and diffusion of dissolved salts depend mainly on the water movements the ordinary coefficients of conductivity and viscosity being negligible in comparison with the effect of large and small-scale turbulence and water transport. The transmission of light is influenced to a large extent by the presence of suspended particles The chemical processes are thus intimately related to biological and bacteriological activity

Temperature

The main problems are those of charting the horizontal and vertical differences, and of studying the varying balance between incoming and outgoing radiation and other

heat exchanges, which lead to important seasonal and irregular changes

The measurement of the sea surface temperature began to be taken seriously in the 18th century when the thermometer was used to identify the path of the Gulf Stream, in order to hasten the passage of a ship to Europe, and sometimes to obtain an indication of shoal water. The systematic collection of data was organized at an international conference in Brussels in 1853, promoted largely through the efforts of a U.S. naval officer, M F. Maury, who was subsequently chief of the Marine Observatory at Washington. Maury appears to have been largely responsible for the inauguration of national organizations for the collection and publication of marine weather data, such as the Marine Division of the Meteorological Office.

The surface temperature in the open ocean ranges from about —1 9°C to 30°C, the lower limit being the freezing point of the most saline water found in the polar regions, and the upper limit being reached through the balance between the gain and loss of heat in the tropics, the main factors being the radiation from the sun and cooling by evaporation. The zone of highest temperature is generally north of the equator; it moves with the seasons, but only in a few places does it extend south of the equator. The isotherms tend to run parallel to the lines of latitude, except where there is a strong northward or southward current and in some coastal regions where the surface is cooled by upwelling of colder water, or where the temperature is dependent on the winds blowing from a large continent, such as North America or Asia, which is hot in summer and cold in winter. In the North Atlantic Ocean the isotherms are pushed far to the south on the American side by the Labrador current, and far to the north on the European side by the relatively warm water which has its origin in the Gulf Stream. So great is the difference, that the Canadian harbours are icebound during the winter,

while Norwegian harbours within the Arctic Circle are open all the year round.

Just north of the equator the surface temperature does not change by more than 1°C between the winter and summer season; the greatest differences between the two seasons occur where the temperature is largely dependent on that of a neighbouring continent, 20°C off the China coast, 17—20°C in the Black Sea, 15°C on the American Atlantic coast, 10—15°C in the North Sea and 10—14°C in the Mediterranean Sea.

One objection to a monthly temperature chart based on the averaging of ships' observations for that month over a great many years, is that it presents too smooth a picture; continuous recordings by ships fitted with a thermograph show that there are often sharp though variable boundaries between different water masses. Records made by Discovery II in the Southern Ocean showed that there were recognizable fronts between Antarctic, sub-Antarctic and subtropical water masses.

The first temperature measurements at great depths were made by collecting large samples of water, using a vessel which remained open at both ends while it was being lowered, but closed itself tightly as soon as it was drawn upwards. The vessel was usually coated with some insulating material, and it was assumed that the sample did not change much in temperature as it was hauled through the warmer layers near the surface. Another method was to surround the bulb of a thermometer with a ball of insulating material, such as a mixture of resin, oil and wax, about 3 inches thick; the thermometer had to be left at the deep level for about 12 hours and then raised as fast as possible. The first great advance came with the introduction of the maximum and minimum indicating thermometer in 1815, but the early measurements were uncertain, because the thermometer was given no protection against the high pressure at great depths, which compresses the bulb and has the effect of registering a temperature much higher than the

true temperature This difficulty was overcome by surrounding the bulb with a protecting outer tube partly filled with mercury and evacuated, which allowed the heat to be conducted without transmitting the pressure. After further improvements the instrument allowed a deep temperature to be measured to an accuracy of 0.1°C, though it suffered from the fundamental disadvantage of being able to record only the maximum or minimum temperatures occurring in the water column through which it was hauled; a warm undercurrent sandwiched between cooler layers would not be detected unless it was warmer than the surface water.

Since 1910 it has been possible to measure the temperature at any depth to an accuracy of 0 01°C. The thermometer is turned upside-down in its supporting frame by a mechanism which is released when it is struck by a "messenger" weight sent down the supporting wire When the thermometer reverses, part of the mercury thread breaks off at a constriction and runs down to the lower end. This length is used to measure the temperature at the depth where the thread was broken A special reservoir prevents more mercury from joining it as the thermometer is raised to the surface, and an auxiliary thermometer at the side of the main one allows a correction to be made for the expansion of the separated thread between the temperature at which the thermometer reversed and that at which it was examined Both thermometers are protected against pressure by a stout outer tube, partly filled with mercury and evacuated.

Fig 3—A deep-sea reversing thermometer in upright position as lowered into the water.

Generally two thermometers are sent down together, fixed to a water-sampling instrument whose two ends close

tightly and enclose a sample when the instrument reverses. Six or more of these instruments are attached at suitable intervals on the same wire, so that six depths can be sampled during one hoist. To about half of them a third thermometer, which is not protected against pressure, is attached; this has been calibrated at different pressures, and a comparison of its reading with that of the protected thermometers gives a measure of the pressure, and therefore the depth, at which the sampling bottle reversed. The method allows the depth of the observation to be estimated to within an accuracy of 10 metres, and is generally a much more accurate measure of the depth than that given by the length of wire reeled out, because the ship cannot usually be manoeuvred so as to keep the wire vertical.

The old insulated water-bottle method is still used for shallow depths, the bottle consists of a number of concentric cylinders kept apart by ebonite spacing-pieces, all the cylinders fill with water, and the outer ones insulate the inner one which contains the thermometer bulb This instrument is closed by a messenger weight which slides down the supporting wire. Within the past 10 years several instruments have been developed to measure the temperature of the water down to a depth of about 150 metres without stopping the ship The bathythermograph, which is the one most used, scratches a temperature depth record on a smoked glass slide as it sinks almost vertically on a thin wire running very freely from a small winch The measurement is accurate to within about 0 1°C.

Salinity

The average amount of dissolved salt in sea water is 35 parts per thousand by weight (‰) Some idea of the total amount of salt in the oceans is given by the approximate calculation that the seas and oceans occupy 71 per cent of the earth's surface, their mean depth is 2 miles, and if this were evaporated and the salt spread evenly over the whole area it would lie 200 feet thick.

The principal chemical ions present are chlorine, sodium, sulphate, magnesium, calcium and potassium, but there are few elements that have not been detected in small traces. It was shown as long ago as 1819 that all specimens of sea water, from every part of the world, contain the same dissolved salts in the same proportions to each other. They differ only in the total amount of dissolved salts, and in very small concentrations of substances involved in biological and bacteriological processes. This constancy of composition makes it possible to use the determination of any one of the major constituents as a measure of the others and of the total salt content. The standard method of measuring salinity is by volumetric estimation of the chlorine ion together with the small amount of bromine and iodine; it is made easier by the issue of sealed tubes of sea water of known salinity for use as standards. The only chemicals taken directly from the sea on a large scale are common salt, magnesium and bromine.

The salinity of the surface water in the open ocean depends mainly on the balance between rain and evaporation. It is least in the Arctic and Antarctic regions and in the tropical rain belt, and greatest in the drier subtropical regions. Much of the surface water in the Arctic Ocean has a salinity less than 32‰ during the summer; in the Antarctic Ocean the salinity does not fall much below 34‰ except very close to melting ice, in the tropics there are extensive areas with less than 35.5‰ in the Atlantic Ocean, and less than 34.5‰ in the Pacific Ocean. Exceptionally low values are found in the Baltic and Black Seas, and near large rivers; and an exceptionally high value of 40‰ in the Red Sea.

In high latitudes the salinity is least in summer when ice is melting, and greatest in winter when the water is freezing. In temperate latitudes the variations are irregular, but the water is usually somewhat more saline in spring than in autumn.

Density

The weight of sea water depends on its temperature, salinity and pressure. The effect of each of these variables ■ accurately known, and the most practical method of finding the density at a particular depth is to calculate it from measurements of temperature and salinity Warming of the water, and the addition of fresh water from rain, rivers and melting ice, reduces the density, cooling, evaporation and freezing increase it.

The distribution of density in the ocean ■ closely related to the water circulation The differences in density between cold and warm regions and between areas of low and high salinity, together with the effect of the wind, are sufficient to keep even the deepest layers of the ocean in slow circulation. Where the climate favours the formation of cold or highly saline water, this water tends to sink to a level appropriate to its density, and to spread out horizontally below the lighter waters of neighbouring regions. To compensate for such movement there is an inward flow, generally at some lesser depth, and an upward movement in some other part of the ocean The equilibrium is a dynamic one, and the horizontal differences in density are to some extent balanced by currents and winds. There is generally a marked difference in density between the water in the left and right flanks of a strong current, because the effect of the earth's rotation makes the layers of equal density slope downwards to one side of the current, to the right in the northern hemisphere and to the left in the southern hemisphere.

Water Circulation

We have such ■ fixed impression of the sea as a water surface, that it requires an effort to envisage the continual circulation of water in deep and bottom currents; these can only be studied by measuring the temperature and salinity at all depths, in sufficient geographical positions to allow the construction of vertical sections to show the

distribution of temperature and salinity across the length and breadth of the oceans Charts showing the horizontal distribution at all depths are also used Sometimes the vertical and horizontal distribution of dissolved oxygen, phosphate or nitrate, or similarities and differences in plant and animal populations are used to trace the origin and movements of a water mass

The densest water in the oceans is found at the bottom of the Arctic basin, but it cannot spread southwards to any large extent because it is hemmed in by a submarine ridge which joins the European and American continents through the Shetland Islands, Faeroes, Iceland and Greenland, and by shallow soundings between Alaska and Siberia Water of similar origin formed near the Antarctic continent is not so restricted, and it spreads northwards along the bottom of the Atlantic Ocean, its influence being evident as far north as the Bay of Biscay. Between this latitude and the Shetland—Faeroe—Iceland submarine ridge the bottom water is formed mainly by the cooling of water of relatively high salinity in the sea between Iceland, Greenland and Labrador. Water which sinks in this area spreads far southwards above the Antarctic bottom current and is generally referred to as the North Atlantic deep current

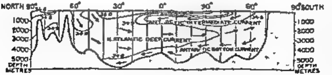


Fig 4—A vertical section through the Atlantic Ocean from North to South showing the distribution of salinity in parts per thousand, and indicating the principal features of the water circulation

On its way it is joined by water which flows as a subsurface current out of the Mediterranean Sea. South of the equator the North Atlantic deep water moves slowly southwards at depths greater than 2,000 metres till it reaches the threshold

of the Antarctic region in about lat. 50°S., and it then climbs relatively steeply above the increasing volume of Antarctic bottom water, till it extends to within about 200 metres of the surface

The third important layer also has its origin in the Antarctic region, but it consists of water which, although cooled, has been diluted to such an extent that it finds its appropriate density level above the warmer, more saline water in the North Atlantic deep current. In the Antarctic zone it is a surface current, spreading east and north, but as soon as it reaches the latitude where the North Atlantic water climbs from 2,000 metres, it sinks to a level intermediate between the North Atlantic water and a tropical and subtropical subsurface layer. Because of its relatively low salinity this Antarctic intermediate current can be detected as far as 25° north of the equator The corresponding Arctic current is much less well developed, and it can only be detected north of Newfoundland, in the western half of the ocean

The water circulations in the Indian and Pacific Oceans have some significant differences from the Atlantic circulation. In both, there are northward movements of Antarctic origin along the ocean bottom, the Antarctic bottom current has its origin chiefly in the south-west corner of the Weddell Sea, south of the Atlantic Ocean, but it spreads eastwards round the Antarctic continent mixing with the overlying deep water and moving away to the north. In the Indian Ocean the overlying deep current begins with a relatively small volume of highly saline water, which appears to spread into the ocean from the Red Sea, in a movement similar to that of the water from the Mediterranean Sea into the Atlantic Ocean, but the main southward movement appears to be composed principally of water which turns back to the south from the Antarctic intermediate and bottom currents. In the Southern Ocean the deep current includes a large volume of North Atlantic deep water which turns eastwards south of the Atlantic Ocean.

In the Pacific Ocean there appears to be no appreciable sinking of highly saline water from the surface to the deep layer, and the deep southward movement is composed entirely of water carried southwards from the intermediate and bottom currents. A remarkable feature of the bottom current is that it contains a large volume of water carried eastwards from the Indian and Atlantic Oceans, with the result that water sinking from the surface in the North Atlantic Ocean plays an unmistakable part in maintaining the salinity of the deep layers of the Pacific Ocean

The existence of extensive deep and bottom currents was recognised, as long ago as 1812, as the most reasonable explanation of the presence of cold water at a moderate depth below the equator, where the surface water is usually warmer than 27° C, while the temperature at 1,000 metres is less than 5° C., and the temperature at the bottom about 1° C. The earliest workers assumed that the sinking of cold water in high latitudes was balanced by an ascending movement in the equatorial region, but although the somewhat nearer approach of the deep currents to the surface, and the very sharp decrease in temperature below the surface, give some indication of such a movement, there is no direct transfer of water from the deep layers to the surface

The principal facts outlined in the previous paragraphs have been discovered during the past 20 years, the improved methods of sampling and measuring salinity making the work much easier. There are still many important problems to be solved; little is known of the speed of the deep water movements, but they are probably not faster than 1 or 2 miles a day, and must be regarded as slow creeping movements rather than currents. They must also be subject to appreciable seasonal fluctuations, especially when they depend, like the Antarctic bottom current and North Atlantic deep current, on the sinking of water mainly in the winter months. The brief outline which has been given here has emphasised the meridional or world circulation,

but when the subject is approached in detail it is found that the zonal movements are also important, and also that mixing and large-scale water exchanges between the different layers must be taken into account.

The effect of the wind on the surface of the ocean is not to drive the surface water straight before it, because the additional forces due to friction with the underlying strata, and the effect of the earth's rotation, are sufficient to direct the movement to the *right* of the wind in the northern hemisphere, and to the left of the wind in the southern hemisphere. The most complete mathematical solution obtained so far shows that the surface drift should be inclined at 45 degrees to the direction of the wind, also that the velocity should decrease with depth, and the angle between the drift and the wind should increase with depth so that the resultant transport of water, between the surface and the depth at which the velocity becomes negligible, is directed at right angles to the direction of the wind. These

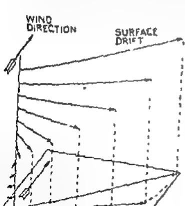


Fig 5
Diagram illustrating the inclination of the surface water drift to the direction of the wind, and the increasing deflection of drift with depth (after Ekman).

results are modified near a coast; and in shallow water the direction of the drift conforms more and more closely to that of the wind Observations have supported the conclusion that the direction of the surface drift in mid-ocean is inclined at approximately 45° to the right of the wind in the northern hemisphere, and 45° to the left in the southern hemisphere, but the changes in velocity and direction with depth have not been thoroughly investigated A recent paper published in the U S A shows that the well-known "Portuguese man-of-war", a stinging jellyfish floating with the help of an air-sac which projects above the surface and acts as a sail, is *oriented physically to sail to the left of* the wind in the northern hemisphere, and to the right of the wind in the southern hemisphere The specimens taken in the northern and southern hemispheres are mirror images of each other (compare a left and a right hand), so designed as to counteract the drift of the water

A persistent offshore wind leads to marked upwelling of water from the subsurface layer. Upwelling is also found where a current flows with a coast on its left in the northern hemisphere, or on its right in the southern hemisphere; this is due to the effect of the earth's rotation, which causes the layers of equal density to slope upwards towards the coast

Tides

The exact knowledge of the attractive forces that generate the tides, and careful analysis of a long series of tidal records, allow future tides to be predicted with great accuracy. The only appreciable differences between the figures given in the tide tables and those obtained by measurement are due to weather factors which cannot be predicted. The theoretical study of tides, although hardly likely to achieve such an ultimate object as the calculation of the tides at any point without any previous observations in the neighbourhood, has made great progress towards explaining how some of the seas and oceans respond to the accurately known tide-raising forces.

The old theory that the tides of the world were due primarily to a tidal wave passing round the Southern Ocean, from which secondary waves travelled northwards, has been proved inadequate, and it is being shown that the tides in the Atlantic Ocean, for example, are produced in the ocean itself. It has been found that the observed tides are much greater than would be expected from the simplest mathematical consideration of the attractive forces, and it is concluded that there are standing oscillations, resonating with the attractive forces

The principle is simply illustrated by imagining a rectangular dish, in which the water oscillates with a see-saw movement, so that there is a large rise and fall at the two ends, and none along a nodal line through the middle

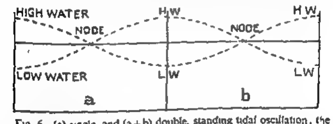


Fig 6—(a) single, and (a + b) double, standing tidal oscillation, the dotted lines indicate the water surface at different times

In Nature the nodal line would shrink to a nodal point, because the effect of the earth's rotation on the streams passing through the central region would cause changes in the surface height on the two sides of the channel In the northern hemisphere the tidal oscillation will appear to rotate in an anticlockwise direction round such a point, and cotidal lines, joining points which have high water at the same time, will radiate from it The point is called an amphidromic point; it must be noted that although there is little rise and fall near such a point there are strong tidal streams. The rotation of the tide-producing forces round the sea also operates so as to produce an amphidromic system.

The English Channel behaves as if there were a barrier across the Straits of Dover, and an approximation to a nodal region near the Isle of Wight. The North Sea behaves as it there were a triple oscillation, with amphidromic points east of Lowestoft, west of Esbjerg and close to Stavanger In such small channels and seas which are offshoots of the main ocean the tides are maintained by the oceanic tides It is often remarked that the tides of the Mediterranean Sea are very small, but it has been shown that they are approximately what would be expected from the action of the attractive forces on such a relatively small sea.

Authorities on tides still find it necessary to contradict the common belief that double high waters such as those at Southampton are due to a difference in time between the arrival of the tide from two directions, in this instance the first high water is attributed to the tide reaching the port from the west, while the second is said to be due to the tide which approaches from the east round the Isle of Wight.

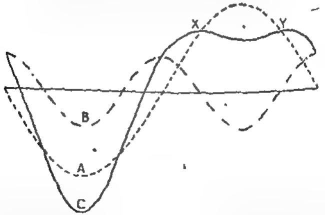


Fig. 7—Tidal curve A has tidal curve B, of half the period, superimposed upon it When both low waters add together, an even lower water C is produced, but when high water A and low water B coincide, the resultant is two modified high tides X and Y

The fundamental fallacy in this explanation is that two tides of the same period cannot combine to exhibit another periodicity, such as the two hours between the double high waters. It is known that when a tidal wave runs into water of decreasing depth the harmonics of the main period are generated (i.e., the shallower water starts to oscillate on its own with quicker rhythm), and they are called terrestrial or shallow water tides. A complete explanation is not available for Southampton, but the essential reason is that these shallow water tides, whose periods are a half, third, quarter and so on, of the main period, are sufficiently out of step with the main tide for the vertical movements to add up to give two high waters

Farther along the coast, at Portland, they add up to give two low waters or a prolonged low water. One of the fundamental conditions for the formation of double tides is that the amplitudes of the harmonics should be appreciable compared with that of the main tidal period, and as a rule this will only occur near an amphidromic point

Waves

Although waves and swell have been studied seriously for more than a century, there are many questions of primary importance which cannot yet be answered As soon as the need for accurate information became urgent during the 1939-1945 war, the available empirical relations governing the generation and travel of waves and swell were found inadequate

The difficulty of measuring waves, and the undiscerning nature of visual observations, have been mainly responsible for the lack of accurate information, and the recent development of wave-recorders and wave analysing apparatus by Admiralty scientists should ensure rapid progress In soundings less than 20 fathoms the waves are measured by pressure recorders, or inverted echo-sounders, laid on the sea bottom, in deep water they are measured by recording the up and down movements of a buoy.

Fig 8—A record of ocean swell obtained with a pressure recorder on the sea bottom at a depth of 100 ft The average height of the swell is 18 inches, the white marks on the time scale at the bottom of the record are 20 seconds apart

Every storm generates waves of all lengths up to a maximum which depends on the greatest wind strength; the shorter waves are generated first, while the wind is rising. They pass out of the storm area as swell on their way to distant coasts, but are soon overtaken by longer waves generated when the wind reaches its greatest strength, the longer waves travelling fastest because the velocity of a wave is directly proportional to the wave period. The first indication of the products of such a storm at a distant recording station is the arrival of low long swell, subsequent recordings show a continual decrease in the period of the swell though the amplitude increases till it reaches a peak value, after this maximum the amplitude decreases as well as the period Generally there are wave trains from several storm areas arriving at the same time and the wave pattern is a complex combination If it happens to be a fairly simple one the waves arrive in groups, first they reinforce each other and there is a group of high crests, and then, as they get out of step, a group of low crests The intervals between the groups depend on the range of periods present, so that it is not necessarily the fourth, fifth, seventh or tenth wave that is the highest; there will be some obvious rhythm if there are not too many periods present.

The success of attempts to trace each wave band back to its origin, and the value of swell recordings at a coastal station for the study of the waves generated in distant storms were found to depend on the certainty with which the various wave periods hidden in a complex record could be separated out. As soon as this was realised a wave

analyser was made to analyse each wave record into a wave spectrum, in which the groups of waves due to any particular storm can usually be distinguished By comparing

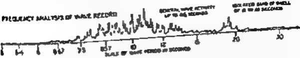


Fig. 9—The frequency analysis of the wave record of which Fig 8 is a part It shows general wave activity from winds in mid-Atlantic, and an isolated band of swell from an intense storm off the coast of Virginia.

many such spectra with the relevant meteorological charts it has been shown that a group of waves of any particular period advances across the ocean with the velocity which classical wave theory had already assigned to it; and since the rates of travel, and times of arrival of different groups can now be obtained with fair accuracy, the trend of periods shown by a particular wave band in successive wave spectra can be used to calculate the distance of the storm from which it emanated

The Admiralty wave recording station is at Perranporth, and the swell that reaches it can usually be traced to storms in the North Atlantic Ocean, sometimes to relatively small but intense storms as far away as the coast of Florida. On at least two occasions it has been possible to detect swell, whose slow decrease in mean period shows that it was generated at a distance of 6,000-7,000 miles from the recording station, and such swell can only be attributed to a storm in the Southern Ocean, probably near Cape Horn.

One immediate advantage of the new recording and analysing techniques is that they can be used, when necessary, to obtain warning of the approach of heavy swell. The warning is obtained by detecting the very low long swell that is first to arrive from a distant storm, but which cannot usually be detected by visual observations because it is obscured by shorter, steeper waves. Wartime requirements

have attracted much attention to the study of waves and considerable progress should be made in the next few years.

4. *Oceanography and Meteorology*

The currents and the temperature and salinity distributions in the oceans represent a dynamic equilibrium between the influence of radiation, conduction, evaporation, precipitation and winds, and much of the energy that maintains the circulation of the air is supplied by such interaction. In some parts of the world the currents are such that the supply of energy from the ocean to the atmosphere is localised, there especially, the sea exerts a profound influence on climate and weather.

The applications of hydrodynamic theory to the study of the distribution of temperature and salinity in the oceans are very similar to the treatment of problems of atmospheric circulation, and as more is done to study the movements of air masses, the two sciences have more in common

5. *Life in the Sea*

It is still easy by fishing or dredging in deep water to discover a new marine animal, but the emphasis in marine biology is moving from the collection of small samples from little known regions to the systematic study of whole populations, especially the dependence of successful reproduction and growth on the physical chemical and biological conditions in the environment. To study a single species involves extensive investigation of the whole life history, from the eggs and larval stages to the spawning adult, each stage may have its own particular requirements, and the factors which control the distribution and fertility of the species will not be understood till such requirements are known

Sea water has been shown to be an ideal medium for supporting life. The necessary minerals and gases are carried in solution; the similarity between the salt content of the water and the body fluids means that no special

energy has to be used to maintain the proper equilibrium, and the buoyancy of the water relieves the animal of the need for supporting itself with a rigid skeleton. The problems of reproduction are simplified by the floating of the eggs and sperm, and the water circulation brings the animal within reach of its food, or brings food within reach of the sedentary species. Such factors may explain why the sea supports animals much larger than any that have existed on land, and the absence in marine animals of the relatively high mentality displayed by many animals on land. It is remarkable, however, that some of them, like the eel, are able to direct themselves on long migrations

With few exceptions marine animals from groups with freshwater representatives are larger than their relatives in fresh water, and often the difference is very great. A better food supply, the similarity of the salt content of the water and the body fluids, and easier respiration because of the presence of carbonates to facilitate the removal of carbon dioxide, may be the chief causes

The vast bulk of life in the open sea is composed not of active creatures such as fish or whales, but of microscopic plants, and small animals which drift with the water They are known collectively as plankton, from the Greek word for wanderer, the plants are known as phytoplankton, and the animals as zooplankton But although the actively swimming animals can constitute only a small proportion of the animal life their total must be tremendous The annual catch of food fishes is approximately 10 million tons.

Fig 10—*Euphasia Superba*, the species of oceanic zooplankton which is the food of the Atlantic whales Probably more is known of the life history of this species than of any other oceanic species. The adult grows to a length of about 3¼ inches

It is the microscopic plants that support the enormous animal populations; the larger sea weeds either attached to the bottom, or adapted, like those in the Sargasso Sea, to a floating existence, are relatively unimportant. The phytoplankton can only exist within the relatively shallow layer, usually much less than 100 metres deep, in which there is sufficient illumination during the daylight hours for the plant's photosynthetic processes, the phytoplankton will die if it sinks below this zone unless the water circulation

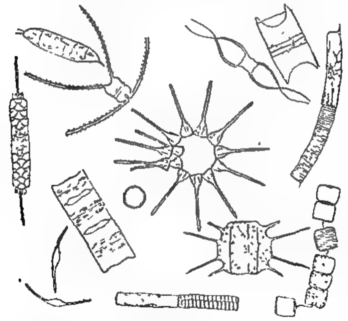


Fig 11—Typical phytoplankton Diatoms, the largest of which is less than 1/100 inch

brings it back The microscopic size of the plants, and the consequent high ratio of surface area to volume favour a low rate of sinking, and they often have long spines or

hair-like projections by which they are virtually suspended in the water. Their specific gravity may also be lessened by the presence of oil in their cells The most specialised forms are found in the warmer waters, possibly because of the somewhat lower viscosity.

The phytoplankton feeds on the dissolved salts and gases in the water. In the temperate regions there is little growth during the winter, and a rapid multiplication takes place in the spring, at a time dependent on the increasing daylight, and on the warming of the surface water which restricts the vertical turbulence and the possibility of removal from the illuminated zone. At this time the water may become very green and acquire a weedy smell, but the crop soon diminishes, probably because it is rapidly consumed by an outburst of animal life which occurs at about the same time. Its recovery is hindered by a shortage of nutrient salts, the available phosphate and nitrate being very much depleted by the first outburst, and only very slowly renewed from the underlying layers, because the warming of the surface water has greatly increased the stability of the water column and restricted vertical mixing There may also be some physiological factor In the autumn there is generally another though smaller outburst, which is attributable to the replenishment of the nutrient salts in the surface layer by increased convection with the underlying layers in the colder and stormier weather, which comes while there is still sufficient daylight for moderate growth.

In subtropical and tropical regions the seasonal changes are much less marked, although in monsoon regions an offshore wind may cause sufficient upwelling of subsurface water to have a great influence on the fertility in one season. Elsewhere in these regions, except in areas where the current system favours upwelling, the growth of the phytoplankton is limited by the shortage of phosphate and nitrate in the well illuminated surface layer.

One of the most interesting features of animal populations in the sea is the large variations in abundance It is known

particularly of some food fishes that one year may be exceptionally favourable, with catches far above normal, and that this may be followed by several years of scarcity. There are also a number of instances in which areas that have been the scene of a profitable fishery have been entirely abandoned by the fish on which the industry was based, or a profitable fishery may develop, like that in the Barents Sea, in an area which had previously not been worth visiting These fluctuations are studied in detail by fishery laboratories, particular attention being paid to the conditions of spawning and the early months, which are believed to be the most critical periods in the life of a fish.

The area in which a particular species lives is often sharply defined Many of the zoologists who have examined the Discovery collections have remarked on the significance of the boundary between Antarctic and sub-Antarctic waters as a biological boundary Among the floating and drifting plants and animals there are many species which are typical of either Antarctic or sub-Antarctic water, and sufficiently rare on the other side of the boundary to be regarded as intruders if found there. Others are common to both sides; there is a similar division of the fishes and shallow bottom-living animals. There is a second boundary farther north between many sub-Antarctic and subtropical species

6. *Research in Oceanography*

Until the present century work in oceanography was mainly descriptive, devoted to measuring depth, taking samples of the sediments, observing temperatures, densities and currents, and collecting specimens of the flora and fauna; the generalisations that were made were concerned chiefly with the geographical distribution of the various properties and species. The next stage was analytical and the results of theoretical studies and laboratory research were used to assist in discovering underlying physical, chemical and biological principles. The energetic application of such methods was begun mainly in Scandinavian

countries in about 1900, and has since spread to all the principal nations. There is no sharp division between the two stages; descriptive work still goes on and there is plenty of scope for it; another continuous process is the improvement in techniques and extension of facilities.

A third stage was introduced when the results of oceanographical investigations could be applied to economic problems. Such an application developed first in north-western Europe, where the fisheries were expanding so rapidly that the fear of overfishing caused all the interested nations to devote considerable attention to the research necessary for obtaining reliable information on which to base regulations for controlling the industry This work also led to the founding of an International Council for the Exploration of the Sea

Although the activities of these laboratories and the official international organisation are restricted to economic problems, they have made large contributions to oceanography. Their approach to the subject, and that of the marine biological stations which they have to some extent supported, has been mainly biological, and physical oceanographers feel that too little attention has been paid to the fundamental physical processes which have a direct bearing on all events in the sea. The need for securing such information is receiving more attention as time goes on, and research carried on during the war has demonstrated new applications of the physical studies to navigation, and to work on coasts and harbours, sufficient to create a fresh demand, and to attract an increasing number of physicists and mathematicians Physical problems are discussed by the Association of Physical Oceanography, which is a branch of the International Union of Geodesy and Geophysics, meeting every three years in normal times, to receive papers dealing with a wide range of subjects It is affiliated to the International Hydrographic Bureau, whose interests are mainly the technical aspects of navigation and hydrographic surveying; also to the International Council for the Ex-

ploration of the Sea, and to an International Commission on the Oceanography of the Pacific Ocean In this country, regular meetings for the discussion of oceanography in all its aspects are held by the Challenger Society, whose main object is to promote the study of oceanography.

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Medical News

The Cure of Tuberculosis

THERE are no dramatic communiqués in the war on this front. But there is progress all the same Knowledge of the nature of the disease has grown enormously and naturally this has improved the treatment and saved lives The realisation that tuberculosis in the chest is often an insidious infection creeping silently though the lungs and giving no hint of its presence, has finally led most doctors to distrust their stethoscopes and turn to X-rays. The diseased tissue in the lungs casts a shadow on the X-ray film, an opaque patch in the translucent lung standing out against the fainter shadows of the ribs. Not all opacities in the chest are tuberculous, of course, but the trained eye can usually tell. Routine X-rays of everybody's chest, as in miniature mass radiography, mean earlier detection and diagnosis, and therefore better chance of cure

The chief treatment is still plenty of rest, as in all illnesses where nothing more specific remains to be done, and the aim is to give the body the best possible chance to fight back. But modern surgery has extended the meaning of this prescription. The sick person can rest in bed, but his sick lung can also be rested Normally, with every breath, air is sucked into both lungs and expelled again Both lungs expand and contract passively as the chest wall moves, perhaps twenty times a minute If one lung is diseased it is better kept collapsed and at rest, until it has had a chance to heal, and collapse is brought about by putting air into the chest around the outside of the lung. This may be an easy business or not, depending on the extent of the disease. At its simplest it involves pushing a needle into the chest and putting in air from a syringe—known as artificial *pneumothorax*. But disease may have pinned the lung in an extended state, in which case the adhesions holding it

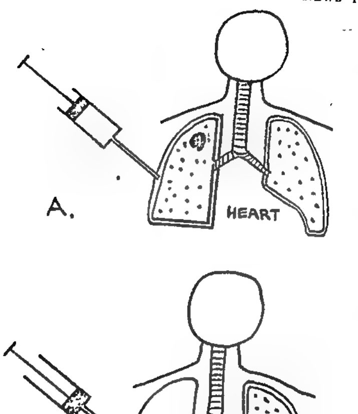


Fig 12—(A) A black patch of disease in the right lung A needle is pushed into the chest, and a syringe-full of air given, when the diseased lung collapses (B).

may have to be cut—a more involved operation, thoracotomy or thoracoplasty. Sometimes, too, the diaphragm is immobilised on one side by crushing its nerve in the neck. Incidentally, it is interesting to see that a man can get along quite well on only one functioning lung (in fact on even less). The same is true of some other organs. One kidney is quite enough, and loss of eighty per cent of the normal liver passes unnoticed.

Another essential of treatment is plenty of good food, and in some hospitals patients are given small doses of insulin half-an-hour or so before meals to stimulate their appetites, so that they are prepared to eat the 5,000 calories of hard manual labour after a day spent in bed. The composition of the food is now thought to be very important. Fats are avoided, and plenty of protein and starches supplied.

With one exception, all medicines so far are disappointing. Sulpha drugs have no effect, penicillin probably not either (some scientists say it may work in colossal doses), streptomycin is doubtful,* and the synthetic drug Promin, a sulphone, is too poisonous to man for use in the necessary high dosage, though it works well in the guinea pig. The exception is a recent discovery. Tuberculosis can attack not only the lungs but also most other parts of the body—bones and joints, kidneys, glands, brain, and skin. In the last mentioned the disease is known under the Latin name of Lupus vulgaris, and during the last four years, it was accidentally found in France, and independently at St. Thomas's Hospital, London, that vitamin D taken in very large doses by mouth would cure tuberculosis of the skin. This is very encouraging, and the pity is that tuberculosis elsewhere appears to be unaffected. The explanation is probably that vitamin D does not attack the germ, as other drugs may, but has the peculiarity of stimulating the skin's resistance to infection, prompting it to heal.

* There is some evidence that streptomycin will cure brain T.B.—tuberculous meningitis, usually a fatal condition.

This question of a drug to destroy the germ is a present spearhead of research, and is being tackled in two ways. One is a wide search for an antibiotic like penicillin or streptomycin. Thousands of moulds and bacteria are being tested to see if they produce any substance which will stop the growth of the tubercle germ in the test-tube. Any promising ones are tested further on experimental T B. in guinea-pigs So far, there is nothing noteworthy in this line.

The other approach is long-term, a study of the chemical behaviour of the living germ, what vitamins and foodstuffs it requires, how it breathes and grows, what chemicals it produces. *We already know that one substance it makes is* a branched-chain fatty acid called phthioic acid, which produces most of the signs of the disease, including the microscopic appearance of the tissues, when it is injected into the body This is promising, but difficult ground However, the further knowledge extends, the greater the chance of turning up a good treatment.

The difficulties of this research are many. Tubercle germs grow very slowly, so that every test takes weeks They are covered in fat, which makes them difficult to handle (and difficult for likely drugs to get in and kill them) Tuberculosis in guinea pigs and other animals is not the same as in man, and what cures a guinea pig may be useless to a human.

There is however another approach to the T B. problem which has been neglected in the past, the study of resistance. Present-day medicine has good evidence for believing that every town-dweller who reaches the age of 21 has actually had tuberculosis once—and got over it. All infections appearing after that age are to be regarded as a breakdown of resistance acquired during the initial childish infection, perhaps as a lighting-up of the old illness previously successfully held at bay. Study of the statistics shows that people with diabetes are much more likely than the average to get this lighting-up. On the other hand, people with "popeye" goitre, the disease of the thyroid gland called thyrotoxicosis, never get a flare-up of T.B.

Countrydwellers rarely get a chance to catch a "touch" of T.B young, since they live under healthy conditions, and when they come to town they have no resistance built up over the years and they go down with it badly This explains for instance why so many Irishmen in London get T.B. It explains, too, why so many young people called into the Forces in 1939-45, and living in crowds for the first time, went down with the infection They had no resistance We need to know what exactly this resistance is, and how to stimulate it, and then we may have a final answer to the T.B. problem

Paludrine for Malaria

When a malaria mosquito bites a man it injects malaria organisms in its saliva into his blood There they mostly infect the red blood corpuscles and destroy them But a few hide away in his tissues, bursting out now and then with fresh bouts of fever; while a few more circulate quietly in the blood, doing no damage, but waiting to infect some fresh biting mosquito. The drugs quinine and mepacrine attack only the organisms actively destroying blood cells They leave alone those in hiding and those lurking for a pick-up, so they are not ideal medicines There is a third drug, Pamaquin, which has a wider effect, but it is too poisonous to the patient to be extensively used.

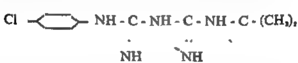
Working on new lines, I C I chemists have developed a fourth drug, Paludrine, which seems to be the best yet, since it is active against the malaria organism in all its forms, wherever it may be. It acts so quickly that it can stop the appearance of the disease if taken after an infected insect bite. This means it should be capable of preventing spread from man to man by insects, and so prevent epidemics. It has the advantage, too, of being harmless to the patient in the necessary dosage, and it does not make him bright yellow as mepacrine so often does

The drug was worked out on bird malaria first, using infected young chicks as the experimental animals This has

the advantage of great sensitivity. The chick needs less medicine than the human, being so much smaller, and this made the chemical work much lighter, since less of each substance had to be made for testing.

Previous anti-malarial research modelled itself on quinine or on the yellow antiseptic acriflavine The I.C.I. men started on something quite different. the pyrimidine ring, an assemblage of atoms found in uric acid, in the chromosomes of the nucleus of living cells, and widely in all living things. They chose this chemical starting-point because of its wide distribution and apparent importance in living things, thinking of the present theory, that the best drugs resemble vitamins and other natural substances fairly closely. Also, a sulpha drug made containing a pyrimidine ring as part of its molecule had shown slight activity against malaria. And they felt that a completely fresh start was needed in this work if any good results were to be obtained

They tried modifying the ring in various ways and finally opened it out and hit on the very potent paludrine.



Stammering

A little while ago Professor Stanley Cobb of Harvard put forward the idea that stammering is essentially due to a lack of balance between the two hemispheres of the brain. The brain is a symmetrical organ, and centres of activity can be recognised in both halves of it, the left half controlling the right side of the body, and the right hemisphere the left side Thus what the left eye sees is transmitted chiefly to the right-hand part of the brain at the back of the head; and the left arm and left leg are under the management of a piece of brain just above the right ear But of course the two halves of the brain work together in a common plan, so

that we can walk, and play the piano, and synthesise what we see through both eyes into one stereoscopic picture. Yet though they work together, one half may actually to a certain extent dominate the other. Most people are right-handed, for instance, which argues dominance by the left hemisphere. It is interesting, too, that the region of the brain which controls speaking is found only on the left-hand side, in the left hemisphere· an exception to the statement that the brain is a symmetrical organ, since there is no corresponding zone on the right. Professor Cobb thinks that originally, in the young infant, there may have been one, but it is suppressed by the more dominant left as the child grows—that is in right-handed children. But in the left-handed, he suggests that a speech centre may persist in the right hemisphere as well as the left, and if the two centres issue conflicting instructions to the tongue and vocal cords, stammering results Conflict is most likely to arise where a naturally left-handed child is forced to become right-handed and some observers have reported that such children are frequently stammerers, though it could be argued that this is a symptom of nervousness after bullying.

In a note in the *Lancet* of February this year Dr. Chrysanthis of Nicosia, Cyprus, reports a few figures bearing on the question, obtained by examining 1,133 boys and girls of the local Greek elementary schools. There were 21 cases of stammering, an incidence of 1.85 per cent, to be compared with Belgium (1 4 per cent), *Hungary* (1.02 per *cent*) and the U.S. (0 87 per cent), which demonstrates a significant difference from country to country. This may be due to differences in the difficulty of speaking the national language, since stammering is apparently unknown amongst the Chinese,* who have a monosyllabic vocabulary.

About 50 of the children were naturally left-handed, and over half of these had been trained to write with the right

* Chinese authorities *have* subsequently denied this.

At first the operation was treated with great reserve, or scorned. Then it was taken up in America with some success, and later it began to be tried in Britain, at first only on the hopeless cases, those who had been years in the asylum and had no prospect of ever coming out. The results were startling, because some of these lost souls recovered sufficiently to go home and even go back to work. Now (Feb 1947) the Board of Control has published the results in the first 1,000 cases treated in the asylums of England and Wales No less than 35 per cent of these were able to go home, two-thirds of them fully recovered Another 30 per cent were much improved, and easier to nurse and care for Many of them were schizophrenics, who still had their delusions or hallucinations after the performance of prefrontal leucotomy, but no longer paid attention to these symptoms. Thoughts of suicide went, depression and agitation fled, they calmed down: 242 people went back to normal everyday life There is still much scientific investigation of this new treatment to be made. What is, after all, a mutilating operation cannot be lightly undertaken. But the first results suggest a great hope.

Cosmic Rays

BY GABRIELE RABEL

Problems and Principles

ABOUT fifty years ago, one or two physicists were puzzled by the fact that their electroscope slowly but steadily lost its charge without apparent reason. They wondered what was wrong and the systematic pursuit of this humble question opened up a new department of science, revealed the existence of the Meson, an otherwise hidden building brick of matter, created a powerful tool in nuclear research, provided evidence for the transformation of energy into matter and vice versa, and may bring us information about the magnetic fields of the sun and possibly of the galaxy. Among the many exciting adventure stories of science, the story of the cosmic rays is one of the most thrilling

The problem facing the physicists was this

An electroscope leaks when the air around or inside it is ionised and conducts electricity. Such ionisation can be produced by light or the radiation emitted by radium. But even when the electroscopes were shielded by thicknesses of lead or water which absorbed and eliminated all known radiations, the leakage continued Consequently there seemed to exist an unknown radiation of unparalleled penetrating power. Its ionising action was small but unmistakable From four to nine pairs of ions were formed per second in a cubic centimetre of air which contains 10^{19} molecules (10 with 19 noughts after it)

Where did this mysterious radiation come from? And what was its nature?

Did it emanate from rocks? Electroscopes were taken out to sea. The leakage remained the same, rocks or no rocks.

Was it of terrestrial origin? In this case it should have disappeared some distance above the surface of the earth,

but it did not. On the contrary, balloon ascents undertaken by Hess and Kolhoerster in 1912/13 showed that from three to four kilometres upwards the ionisation even increased and at an altitude of nine kilometres was twelve times as strong as at sea level.

Did then the radiation originate in the upper atmosphere? Or was it of cosmic origin? And, if "cosmic," did it hail from the sun and nearby stars or from regions beyond our galaxy?

Further, to what class of radiation did it belong? Was it a kind of super-X-rays, electrically neutral like light but of incredibly short wave-length? Or did it consist of material corpuscles, possibly electrically charged like those emitted by radium?

None of these intriguing questions was answered when the first world war interrupted the work for ten years.

In 1925, R. Millikan gave new impetus to the research. He followed the "ultra-penetrating radiation," as it was then called, down under water, "cannily selecting only snowfed mountain lakes where the water, never having been underground, was uncontaminated by radioactive materials" He also sent up 15 km into the atmosphere unpiloted balloons which carried the whole experimental equipment crowded into a space of six inches overall and weighing seven ounces

He established as a fact what Hess and others had long surmised, that the atmosphere was not the primary source of the radiation but acted only as an absorbent. From now on the designation "Cosmic Rays" was generally adopted.

E. Regener, extending these measurements up to 30 km., registered in an altitude where the air pressure had sunk to 10 cm mercury, a maximum of ionisation, 200 times the value at sea level. Still higher up the value decreased again. (See below, p. 125) Regener also recorded penetrating radiation as far as 235 metres under water.

A new and decisive phase set in for cosmic ray research when the Geiger-Mueller counter and Wilson cloud chamber

were introduced into it. These devices have been fully described in *Science News II* in the chapter "The Tools of Nuclear Physics" The counter gives an electric discharge each time an ionising particle passes through it and the number of discharges is mechanically counted and recorded The cloud chamber contains moist air which is cooled by sudden expansion and condenses around electrically charged particles The path of each such particle thus appears as a cloud track which can be observed and photographed. Application of a magnetic field deflects the particles, the sign of the charge being given by the direction of the deflection.

Whereas until 1930 only the amount of ionisation could be measured by means of electroscope and ammeter, it was now possible for the experimenter to analyse the rays themselves, to establish their direction, mass, velocity and electrical status.

The first successful experiments with magnetic fields were those undertaken with the field of the earth. This field is very feeble, only 0.2—0 5 gauss,* against 15,000 gauss or more which may be applied in the laboratory. But on the other hand the terrestrial field, projecting far out into space, could be expected to catch particles on their way from infinity to us, to act on them throughout the atmosphere and keep off all except those possessing enormous quantities of energy.

This debarring action must be strongest at the magnetic equator because in the equatorial plane rays coming in vertically are perpendicular to the magnetic field Particles coming in vertically at the poles should approach the surface freely because a magnetic field does not act at all on charges moving in the direction of its own axis. We consider here only vertical incidence. Outside our atmosphere the cosmic rays are supposed to have no privileged direction; within our atmosphere, however, vertical rays

* The gauss is the unit of the magnetic field. It exerts unit force (1 dyne) on a unit magnetic pole placed in it

having the shortest path are the least absorbed—even as the solar radiation is the most intense when the sun stands in the zenith

If, then, the new radiation consisted of electrically charged particles, it should be found more abundant near the poles than near the equator. The very first measurements showed a drop of 14 per cent near the equator. But—could not this drop be, partly, due to atmospheric conditions in the equatorial zone?

A. H. Compton decided this question by a shrewd experiment He compared cosmic radiation in Arequipa and Mexico City, both stations 2,300 metres above sea level, both equal as to geographic latitude, Arequipa 19°S, Mexico City 19°N, but not equal as to geo-magnetic latitude, because the magnetic equator runs 10° south of the geographic one

At every altitude the cosmic rays were found to be more intense in Mexico (29° N) than in Arequipa (9° S). In rising to greater heights, Compton found the "latitude effect" even larger.

Contrary to expectation, the intensity of the rays does not increase up to the poles but only to latitude 45° or 50° and then remains constant Several explanations have been offered for this phenomenon, none of them quite convincing or generally accepted.

If cosmic rays are influenced by a magnetic field, they must have a charge. Is it positive or negative? We apply the well-known Left Hand rule. forefinger stretched out towards the north pole, middle finger representing the motion of a *positive* charge moving downwards perpendicular to the field, thumb, perpendicular to both other fingers, indicating that the deflection points to the right, which means to the east. A negative charge would be pushed westwards.

If particles are deflected to the east, they must appear to us as coming from the west. Observation through G.M. counters arranged in line showed a slight surplus of west

over east. As this surplus was greater at sea level than in higher altitudes, it appeared that the most penetrating part of the radiation contained more positive than negative charges.

This result was entirely unexpected, as positive charges had been hitherto known only attached to comparatively heavy and easily absorbed masses

At the same time, 1933, H. L. Anderson, in Pasadena, analysing cloud chamber photographs of cosmic rays, espied an extraordinary display. He saw a pair of cloud trails one of them was the trail of an ordinary electron, but the other was deflected in the opposite direction—an electron with a positive charge had entered the stage It was named Positron.*

Positrons appear only on fleeting visits. Their life-time is about 1 millionth of a second That is why they have so long escaped detection

The most amazing point about positrons and negatrons (electrons) is that the pair of them appear like the conjurer's rabbit out of nothing—if by a "thing" we mean a lump of matter The creator of this pair is not matter but energy.

The equivalence of matter and energy—as postulated by Einstein's theory—is, as Leprince-Ringuet remarks, "vital to the cosmic ray theory and accepted as a proven fact"

If one increases the energy of a body, say by heating it, it becomes heavier. But because the mass m added by an increase in energy E is given by the equation

$$m=\frac{E}{c^2},$$

wherein c, the velocity of light, is $= 3\times 10^{10}$ cm/sec (300,000 km/sec.), so that $c^2=9\times10^{20}$, any ordinarily available amount of energy divided by the factor c^2 is a trifle. Conversely, the equation $E=mc^2$ tells us that for

* A list of atomic particles will be found in the Glossary under "Particle"

a mass of only 1 gram, owing to multiplication with the factor c^2, the corresponding energy is immense.

If a photon, a "grain of light", is to transform itself into an electron pair, its energy must be at least equivalent to the "rest mass" of the two electrons, which amounts to 1 million electron volts

One Mev (=1 million electron volt) is the energy unit used in cosmic ray research. One electron volt can be described as the kinetic energy acquired by an electron when it is accelerated through a potential difference of 1 volt.

One Mev, then, is the threshold for the creation of an electron pair out of energy. Gamma rays from thorium C possess 2 6 Mev, hence they can, and do, turn into electron pairs.

The energies involved in cosmic radiation are far, far above that level. By the fission of uranium, 160 Mev are liberated, but the energy of cosmic rays goes up to several thousand Mevs. Such unbelievably great energies cannot be produced artificially—they are a heaven-sent gift to physicists.

Transformations of photons into electrons and back are in fact a common event in the activities of these rays and can be observed and photographed in the cloud chamber.

Leaving the description of such and other photographs for the second part of this article, we can now proceed to the problem. what is the origin of this radiation?

If it came from the sun, it should fluctuate with the time of the day as all other solar radiations do. But it does not. Nor does it depend on the sidereal day. I cannot resist the temptation to quote Leprince-Ringuet's picturesque decription, although it is slightly exaggerated.

"Since remote times a constant imperturbable hail of implacable constancy has been falling on our earth. It is indifferent to the time of the day, of the season, the position of the sun or moon or even the galaxy, it envelops everything, traverses everything, it traverses our bodies at the rate of several million corpuscles daily, without causing any

damage, but occasionally provoking violent and explosive atomic phenomena."

In reality fluctuations which depend on our motion respective to the sun and stars are observed, but they are very feeble, hardly three per cent, and they are ascribed to deflections by the magnetic fields of the sun and stars acting on rays which pass near by.

As astrophysicists are not yet quite clear about the magnetic field of the sun, cosmic rays might help in solving their problems. The "implacable constancy" of cosmic radiation is also disturbed by magnetic storms The changes produced are the same all over the earth. They are, by some, attributed to a hypothetical ring of electrons revolving in high altitudes

There are scientists who connect the origin of the cosmic rays with the appearance of the so-called "Supernovae,"—stars which for unknown reasons suddenly undergo a tremendous explosion, the most violent castastrophe known in heaven. A Supernova illuminates the entire universe in which it occurs to such an extent that the dim trickle of light which reaches us ordinarily is increased by 25-30 per cent. They are an extremely rare phenomenon. Only ten of them have so far been recorded. And the more common "Novae" do not eject enough mass to fill the whole of interstellar space as cosmic rays are supposed to do.

A great deal of research and speculation is devoted to these vast and exciting problems, and there is no telling what revelations about the universe may grow from that tiny seed—the leaking of an electroscope.

The Meson and its Kin

In 1935, the Japanese physicist Yukawa, attempting to explain the forces which act in the atomic nucleus, assumed the existence of a particle capable of being charged positively or negatively, with a mass about 200 times that of the electron and an exceedingly short life-time.

Two years later, cosmic ray investigators, without any

relation to nuclear theory, happened to hit on a few unusual cloud chamber tracks—tracks which were too thick to be ascribed to an electron and too much deflected by the magnetic field for a proton These tracks could only be due to corpuscles with a mass intermediate between that of electrons and protons It was computed to be 200-240 times the mass of the electron The new particle can have an electric charge of either sign and its average life time is 0 000002 seconds when at rest When it keeps moving, it can live a little longer

Seldom have theoretical and experimental findings converged in such a striking manner!

The newcomer was called Meson by Yukawa, Mesotron by the experimenters. Recently the term mesotron was dropped in favour of meson.

The enormous significance of cosmic ray research can be seen from the fact that the meson has not yet revealed its presence in any other department of physics, not even in atomic disintegration.

If the mass of the meson is taken to be 200 times that of the electron, it requires 200 times more energy for its creation—that is 100 Mev. And as mesons mostly appear several at a time, they represent an amount of energy which, although it *might* be gained from nuclear tranformations, has so far been available only in cosmic rays.

Without delving deep into this difficult subject, we may try to get a rough idea what led Yukawa to postulate the meson.

According to present theory, the atomic nucleus consists only of protons and neutrons, *i.e.*, corpuscles having the mass of a hydrogen atom, the first positively charged, the other neutral.

A proton may become a neutron by abandoning its positive charge, a neutron may become a proton by absorbing a positive or emitting a negative charge. Protons and neutrons, then, are two states of one and the same corpuscle which is now called a Nucleon

Electric charge, like so many other things, has lost its absolute and constant character. Emission of a charge may really be creation of a charge

Negative electrons are attached to the nucleus in external circles—so far away that the radius of a big atom is 20,000 times the radius of its nucleus.

In Bohr's theory of the atom, when an electron passes from one external ring to a nearer one, it emits a photon, a grain of light. This origin of photons, after causing a lot of perplexity, has now been brought in accord with the general theory of electromagnetic fields If an electron is in interaction with an electromagnetic field, it may emit a photon which another electron may absorb. Interaction between electrons means that they can exchange photons.

The electromagnetic field has a wave aspect and a corpuscular aspect The wave aspect shows itself only in comparatively large spaces.

Now, while the forces acting outside the atomic nucleus, including those which bind the external electrons to it, are fairly well understood, *it is completely obscure what forces* obtain within the nucleus and keep the protons and neutrons together. These forces must be immense Neither the laws of electrostatics nor of gravitation can account for them A new type of force, a new type of field is required.

"Mesons," says Leprince-Ringuet, "have been invented by the theoreticians in order to act among the nuclear components a role analogous to that which the photon plays among the electrons"

This implies that the meson must be highly unstable, emitted and absorbed as occasion demands.

The new field which is assumed to exist in the nucleus as a substitute for the electromagnetic field, can, owing to lack of free space, not develop a wave character, but has only a corpuscular aspect.

The corpuscles transport positive or negative charge hither and thither between the nucleons and form the cement which keeps them together—as electrons keep mole-

cules together. These corpuscles, then, are the mesons and the nuclear field is called the *Mesonic Field.*

The reason why mesons have not yet been discovered within the nucleus might conceivably be that they spend their all too short life crowded in between protons and neutrons so as to be indistinguishable from them. Outside the nucleus, however, they allow themselves to be photographed A cloud chamber photo obtained by Anderson and Neddermeyer in 1938 first showed their characteristic trail—more strongly deflected by the magnetic field than a proton would be and thicker than that of an electron.

In a photo made by Williams and Robertson in 1940, we see a meson which ends its path by disintegrating into an electron. The electron gives a much finer trail. If the meson had yielded all its energy to the electron, their paths should form a straight line, but in the photo the electron goes off at an angle. This indicates that the meson dissolves into two particles, one of which apparently is not charged and therefore cannot be seen Even this event, the splitting of the meson into an electron and a neutral particle, baptised the Neutrino, was predicted by Yukawa.

A neutral meson is also expected to appear; the romantic name Neutretto is ready waiting for it.

Apart from the cloud chamber and Geiger-Muller counter, there is another device for making travelling corpuscles record their path. It consists in simply exposing a photographic plate to the incoming rays which act on the silver and the bromide as well as on the carbon, oxygen and nitrogen of the emulsion An emulsion specially fitted for the purpose and designated "Nuclear Research Emulsion" has been recently introduced

Professional atom killers recognise their game from the foot-prints, just as other hunters do. Each trace has a characteristic grain spacing, thickness, total length or range and shows a different degree of scattering or ionisation around it.

D. H. Perkins exposed plates coated with the new emul-

sion for several hours in an aeroplane at about 10 km. height and obtained pictures of atomic disintegrations. One of them was of particular interest. Four paths seemed to emerge from one point, but closer inspection revealed that the originator of one of these paths, as it did not move away from the centre but towards it, must have been the author of the disruption. If, as Perkins assumes, this author is a slow meson, the expectation that cosmic rays would be valuable assistants in nuclear research is fulfilled.

Hitherto neutrons alone were used for the destruction of nuclei; because, not being electrically charged, they are not deflected and slowed down by other charges. They do not ionise. They proceed relentlessly and vigorously until they hit on a nucleus and smash it. This is why neutrons were used to fission the uranium nucleus for the atom bomb.

Mesons can afford to ionise on their way (which they did in Perkins' experiment) and still retain enough energy to smash a nucleus into pieces.

The emulsion photographs have recorded many other interesting examples of multiple disintegration of nuclei. Occhialini and Power found after six weeks' exposure on the Pic du Midi two such "stars" or "explosive beams" per square centimetre on their plates.

Properties of Cosmic Rays

Among the components of cosmic rays, two main groups are distinguished, the soft, *i.e.*, easily absorbable group A, and the hard, penetrating group B.

We must not think that all soft rays have feebler and all hard rays greater energy. The energy distribution is pretty much the same in both groups. Leprince-Ringuet warns against the misconception that the penetrating power of any radiation increases with its energy. How deep into, or through, matter a ray can penetrate, depends on what it does on its way. A ray which wastes energy by ionising or by scattering electrons about, may penetrate less far than one which started with smaller initial energy but preserved it carefully.

Mesons are the most penetrating component of cosmic rays. At sea level they form 70-80 per cent of the total radiation. One can follow them down to 400 m. below sea level and they harden with the depth. Even at 1,000 m below sea level radiation has been detected, but its properties are not yet clear.

Showers If two lead screens are inserted in the path of cosmic rays in the cloud chamber, one may see the track of an electron stopping at the upper plate, then nothing between the plates, and finally, emerging from the lower plate, a pair of plus-minus electrons

The explanation of such a picture is that the electron stopped in the first plate gave rise to a photon (as it does in the cathode tube), that the photon, invisible because it did not ionise, transported energy from plate 1 to plate 2, and there transfigured itself into an electron pair

If electrons thus created have sufficient energy, they may again produce photons which in their turn materialise into pairs of charged corpuscles In this manner, one single incoming electron can produce what is called a "shower" or "burst" or "cascade"

In a dense material such as lead, the multiplication in a few centimetres is so considerable that a hundred times more particles emerge below the screen than entered above.

In the atmosphere the incident particles must traverse a longer path before achieving such a high degree of multiplication. Therefore a shower in air may cover an area of several hundred square metres. Sixty-five Geiger-Muller counters have been used to follow the direction of some of the rays and establish the width of one shower. The number of rays in a large beam is estimated at 100,000, from which one can deduce what fantastic energies the primary radiation must possess. What the primary radiation may be is not known. Some think it consists of protons.

Showers have their maximum at about 16 km. altitude Higher up, there is not enough matter, lower down there

are not enough rays to produce the showers. At sea level, there are very few of them

Showers and soft groups are really the same thing The soft group consists of photons and electrons originally of very great energy which do not penetrate far, *because* they produce showers

As only the most penetrating rays reach sea level, they are extremely rare One millicurie of radium expels thirty million alpha particles per second But only two million cosmic ray particles fall on a human body in a whole day

The energy content of a single ray at sea level is astounding. Most of them have 2,000 Mev, but some as much as 10,000 Mev. If a magnetic field can bend these rays at all, the bending is slight But it always indicates plus and minus charges in a proportion of about five to four

Whether the cosmic rays which pass unceasingly through our body have any biological effect, has not yet been established.

Can the enormous energies contained in the rays not be made to perform more useful work than the destruction of atomic nuclei? Perhaps there will come a day when we shall have tubs in our houses to collect the cosmic rain, one for the positive, one for the negative section, and use it to drive our vacuum cleaners and heat our rooms

FURTHER READING

A book by H B Lemon, "Cosmic Rays So Far," published in 1936, gives a popular and very interesting account of the early stages of cosmic research, not neglecting the human factor

Louis Leprince-Ringuet's book "Les rayons cosmiques" appeared in 1945 and contains recent developments It is written with glowing enthusiasm and tries to convey to the reader a *feeling for the beauty* and grandeur of physical experimental work.

The Control of Flowering

BY PROFESSOR ERIC ASHBY

"Go down to Kew in lilac time," says the poem. The Londoner knows this means go to Kew sometime in May. To see primroses at Kew he has to go there in April, and to see chrysanthemums he has to go in September. This regularity in the gay procession of flowers is a recurring miracle we take for granted. It was familiar to our ancestors when they still gathered at Stonehenge, yet it is still a "live" research problem. Why not primroses in July? Why not chrysanthemums in May? There is no adequate answer yet to such questions as these. In this article I shall describe how far botanists have gone toward finding an answer.

In spring the temperature rises and the light intensity grows stronger. You would immediately suspect that this climatic rhythm is a cause of the rhythm of flowering, and indeed the early or late flowering of any species is obviously bound up with what we call early or late springs and summers. But if you grow a chrysanthemum in a greenhouse at constant temperature, you still cannot persuade it to flower till the autumn; and from such experiments as this you would soon become convinced that although temperature and light intensity *modify* flowering time, for many plants they are not the master key which opens the flower bud.

Even 70 years ago botanists were convinced that time of flowering could not be explained by studying the effects of temperature and light intensity on plant growth. In America attempts were made to add up for various plants all the daily mean temperatures from the onset of growth in the spring until flowering time, and to express these as "heat integrals." This gave very little useful information.

In Germany experiments were done to discover whether certain qualities of light (for instance violet or ultra-violet) affected flowering. This, too, proved to be a fruitless approach to the problem. For a time the hunt was almost given up. It was not until 1920 that a fresh scent appeared, which drew botanists all over the world back into the chase after the cause of flowering

Length of Day

As so often happens in the history of scientific research, the fresh discovery was incidental to an entirely different investigation. Two American scientists, Garner and Allard, were trying to hybridise two varieties of tobacco which inconveniently flowered at different times, and so could not be crossed. They had tried various gardeners' tricks to persuade the two varieties to flower simultaneously The tricks failed to work Then, through a well planned experiment, they made the astonishing discovery that they could control the time of flowering in their tobacco varieties by changing the *length of day*. An autumn flowering plant can be made to flower at midsummer, provided it is shut in a light-tight box at, say, 1 p m. every day, after about eight hours of daylight Or it can be prevented from flowering in the autumn, provided a single electric light bulb is left on in the greenhouse until, say, 11 p m every night. Clearly it was the *duration* of light, not its *intensity*, which determined flowering in the plants Garner and Allard used; for a light intensity too faint to read by was strong enough to affect the length of day. (It has even been suggested since that bright moonlight is powerful enough to affect time of flowering.)

Dozens of research workers took up the scent, and in a few years it was established that flowering plants can be divided into three broad categories: plants that flower in a "long day," plants that flower in a "short day," and plants indifferent to length of day In table I is set out the behaviour of some common plants in this regard. As you

TABLE 1

"*Long day*" *plants*:—	Barley (*some varieties*), *Spinach* (*some varieties*), Wheat, Soybean (some varieties), Beet, Radish, Lettuce
"Short day" plants:—	Rice (most varieties), Chrysanthemum (most varieties), *Cosmos bipinnatus*, *Primula* (some species), Soybean (some varieties), French bean
"Indifferent" plants —	Tomato, Pepper.

interpret this table, you have to be cautious over two points. First, there is no hard-and-fast definition of "long day" and "short day." You cannot say, for instance, that a day-length of nine and a half hours is "short" and a day-length of ten and a half hours is "long" By and large, short day plants flower if they receive 8-9 hours of light a day, and long day plants flower if they receive 14-16 hours of light a day, though the situation is more complicated than this, for recent research has shown that some wild plants are adjusted to the day-lengths of the parts of the earth from which they come Tropical plants, for instance, are adjusted to a day-length of about 12 hours, and some of them will not flower in an English summer because the days are too long. The Russians recently brought to Leningrad some new types of potatoes from Central America, and they had difficulty in getting these to flower, or even to grow properly, in a Leningrad summer, although the potatoes were put in a warm glasshouse

The second point which requires caution in talking of "long day" and "short day" plants is that the reaction to length of day varies with the variety of plant. Tobacco, for instance, is both "long day" and "short day": there are summer flowering varieties and autumn flowering varieties. The same is true of many other plants. In fact only a few species show consistent behaviour in all their varieties. To the best of my knowledge all tomatoes are indifferent to length of day, and all chrysanthemums are short day plants.

The Analysis of Photoperiodism

By 1927 photoperiodism (to give the phenomenon its ugly American name) was recognised as the master factor determining the flowering time of many plants For the last twenty years research workers on photoperiodism have been trying to answer the question by what mechanism does length of day determine flowering? The question cannot yet be answered, but the search for an answer has disclosed some very interesting information Here is a summary of it.

I mentioned just now that the intensity of illumination plays no important part in the effects of length of day Quite a dim light "counts" as daylight. But the quality of light does matter a Russian worker showed that it is the red-yellow end of the spectrum, not the blue-violet end, which affects time of flowering More recently the problem has become more puzzling still, for some American workers have published data which indicate that it may not be the length of *day* so much as the length of *night* which determines flowering They began from the familiar fact that chrysanthemums, for example, flower in autumn in an 8-10 hour day. Then they interrupted the 14-hour period of darkness every night by turning on a light in the glasshouse for a few minutes in the middle of the night. The result of this experiment was that even in short days the chrysanthemums *did not flower.* The few minutes of illumination in the middle of the night cannot possibly affect the length of day, but they do seem to destroy the influence of the long night. This experiment raises a new (and perhaps false) scent: is it a *long night*, rather than a short day, which brings autumn plants into flower? And if it is, how does that brief illumination in the middle of the night cancel out, as it were, the effect of the long night? We do not know the answer to these questions, but the curious phenomenon is already being used by gardeners. If you are growing chrysanthemums for the flower trade, you can postpone *their flowering simply* by switching an electric light on for half an hour in the middle of the night during August and

September. When you want the plants to flower, you discontinue this nightly dose of light.

One of the most remarkable discoveries in the analysis of photoperiodism is that under some circumstances it is sufficient to give the young seedling an initial dose of the correct length of day for ten days or so, and thereafter the plant will flower in whatever length of day it is grown—even if it is grown in continuous light The ten days of photoperiodic induction, as it is called, are sufficient to cause the plant to form flower buds; after that, so long as the plant grows, the flowers are bound to open. This experiment has been done in both America and Russia, on soybean plants and *Cosmos*, both of which flower in short days Not all plants respond to an initial dose of the correct length of day, but there is no doubt about the results from those which do respond

Let us pause for a moment to review the problem. We have on the one hand the surprising stimulus of length of day (or night), and on the other hand the striking response of flowering. We know that it is the red-yellow part of the spectrum which affects time of flowering and that the intensity of light is unimportant. We know that a brief interruption of the dark period by light will cancel out the effect of short days on flowering. We know that an initial dose of short days will condition some plants to flower in any length of day. But what is the bridge between the stimulus and the response? The plant has no eyes: how does it receive the stimulus of long or short day? The plant has no nervous system: how does it transmit the stimulus to the region where flowers are formed? These are questions which bring us to the front line of research in this branch of botany.

Is there a Flower Hormone?

The swiftest advances on this front have been made by two Russian workers: Chailachjan, an Armenian who works at the Timiryazev Institute for Plant Physiology in

Moscow, and Moshkov, who works in Leningrad. Some of their work has been repeated and confirmed in America and Australia.

Chailachjan set out to discover whether the stimulus of length of day was received by the leaves, or the buds where the flowers appeared. He did this by a very simple experiment on chrysanthemums Chrysanthemum plants were decapitated and side shoots were allowed to grow out from the top. The leaves were cut off these side shoots as quickly as they appeared, and also from the upper part of the main stem; so the plants used for the experiment were naked of leaves above (See Figure 13a) Chailachjan divided these plants into four groups. Plants in the first group were grown under normal summer conditions Plants in the second group were covered early every afternoon with a box which blacked out the leaves, but not the bare stems at the top (Figure 13b). Plants in the third group were covered with boxes which blacked out the upper bare stems but not the leaves below (Figure 13c) Plants in the fourth group had both leaves and bare upper stems covered every

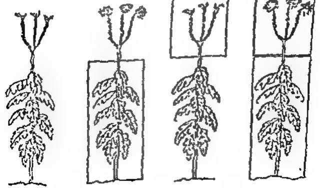


Fig 13

afternoon (Figure 13d). The effect of the boxes was to give short days to those parts of the plants they covered, while the uncovered parts were left in long days. The results of this experiment are illustrated in the figure In long days (13a) the chrysanthemums did not flower. If the *leaves* are under short days (13b), then flowers appear at the top (which was not exposed to short days). If the upper stems are under short days and the leaves below under long days (13c), no flowers appear. If the whole plant is under short days (13d), it flowers It is clear therefore that.—

(*a*) the leaves "perceive" the stimulus of length of day;

(*b*) the top buds, where flowers may appear, cannot "perceive" the stimulus;

(*c*) the stimulus is transmitted up the stem from the leaves to the terminal buds

There is no mechanism in plants corresponding to the nervous system in animals; so how can the stimulus be transmitted from leaf to bud? Previous experience with growth hormones (see the article by K. V. Thimann in Volume 1 of SCIENCE NEWS) leads the botanist to suspect that some *substance* may be produced in the leaves under the correct length of day, may move down the leaf stalk and up the stem into the growing point, and there may cause flower buds to form; in other words that a "flower hormone" made by the leaves, may be the internal cause of flowering Chailachjan has gone so far as to name the suspected hormone "florigen"; but we are scarcely justified in going as far as that yet. To *suspect* that there is a flower hormone is a good working hypothesis, for it enables us to lay plans for future research, by designing experiments which will either confirm or confute our suspicion; but until chemists have isolated "florigen" and have caused flowering by applying it to plants, we have to remember that "florigen" is still a hypothesis, not a substance.

Even though "florigen" is only a hypothesis, we know something of its properties. We know, for instance, that it will cross a graft union; for it is possible to graft leaves

which have been subjected to short days on to a leafless "short day plant" subjected to long days, and to produce flowers. This has been done with tobacco, soybean, *Perilla*, and other plants. For a time it was thought that the stimulus would cross even a non-living junction (namely tissue paper inserted between the stock and scion of a graft), but the data in favour of this have not been confirmed. If it could be proved that the stimulus does not require living cells for its journey from leaf to bud, then the case in favour of "florigen" would be immensely strengthened. Another peculiarity about "florigen" (whatever it is) is that enough is produced by a quarter of a leaf to cause flowering. This was discovered by Moshkov, who grew a short day plant, *Perilla*, on which he left only the fifth leaf. Even such a maltreated plant as this flowers if subjected to short days, and fails to flower if subjected to long days Moshkov then worked with plants carrying only half a single leaf, these too responded to short days by flowering Finally he worked with plants carrying only a quarter of a single leaf and even these usually responded by flowering in short days. A third peculiarity of "florigen" (we must not fall into the assumption that it exists) is that it is destroyed or inhibited in the presence of leaves which are *not* producing it. For instance, a single leaf on *Perilla* will bring about flowering if subjected to short days, but only if all leaves *not* receiving short days have been cut off the plant It seems as though something comes out of the leaves under long days which prevents "florigen" from acting on the buds Chailachjan recently demonstrated this in a series of brilliant experiments on the short day plant *Perilla* He removed all the leaves but one from a large number of *Perilla* plants. He divided the plants into eight groups and treated them as follows:—

Group 1: exposed to long day (about 16 hours)

Group 2: exposed to short day (about 8 hours)

Group 3: lower half exposed to short day, upper half to long day.

affected by length of day. In the "wrong" length of day, potato plants do not form tubers, willows lose their ability to withstand frost, and other trees their ability to endure drought. Even the fall of leaves in autumn may be postponed by an artificial increase in the length of day: this was noticed many years ago in Geneva, where the trees lining some streets did not lose their leaves in autumn because the street lamps were left alight all night.

Chemicals to cause Flowering?

It is pretty clear which way research will run on photoperiodism. There will be critical experiments to prove (or disprove) the existence of "florigen", accompanied by experiments on how it moves from leaf to bud in the plant, and on the possible "anti-florigen" from leaves under the "wrong" length of day. If these experiments favour the existence of "florigen," the chemists will come into the field to isolate it, to determine its molecular structure, and to synthesise it. Then biochemists will try to discover how "florigen" is synthesised in leaves and how it is related to the rest of leaf-chemistry. All this is likely to take years. Meanwhile there is a short cut, which has been tried already, so far without success: that is to add to the plant various substances which might conceivably affect flowering. Occasionally this hit-or-miss research gives useful results. Among the substances administered to plants with this intention are: the juice of leaves subjected to the "right" length of day; yeast extract, sewage effluent; indoleacetic acid (one of the growth hormones); indolebutyric, indolepropionic, phenylacetic, and phenylpropionic acids; vitamins B_1, B_2, B_6; vitamin C, nicotinic acid; pantothenic acid; theelin,* various amino-acids, and several others. None of these substances has indubitably caused flowering. The internal cause of flowering still eludes us. There is very good evidence that *fruiting* (*i.e.*, the development of flower to fruit, and the maturation of fruits) *is* dependent

*Female sex hormone.

on various known chemicals, particularly the growth hormone auxin, the recently discovered 2-4-dichlorophenoxyacetic acid, and the balance of carbohydrates and organic nitrogen compounds in the plant; but that is a topic for a separate article.

the "coefficient of friction." In the case of a brick sliding on a clean wooden table, the coefficient of friction is about 0.5, that is to say, a force equal to one-half the weight of the brick is required to pull it along. The coefficient of friction varies widely for different solids. With ice sliding on ice, for example, it is about 0.02 to 0.03, so that a pull equal to about 1/50th of the weight of the ice block will cause sliding. With copper sliding on copper, the coefficient of friction is about 0.8 to 1.0, and, if the metal is carefully cleaned, so that all traces of surface contamination are removed, it may rise to a very much higher value still. The third law is that the friction is independent of the speed of sliding. Experiments show, however, that this is true only between narrow limits, and at high speed the friction usually decreases. In fact, all three of these "laws" can only be regarded as crude approximations. Nevertheless, it is found that the first two of them are approximately true over a wide range of experimental conditions.

Now why is there this resistance to motion? What is the mechanism of friction, and from the point of view of a molecule sitting on the surface, what is really happening during sliding? We may ask a few simple questions and then endeavour to answer them by direct experiment. To begin with, we may ask three questions. (i) What is the real area of contact between the solids? (ii) What is the surface temperature of the rubbing solids? (iii) What is the nature of the surface damage?

The Real Area of Contact between Solid Surfaces

It is a very difficult matter to prepare surfaces which are really flat. Even on carefully polished surfaces, hills and valleys which are large compared with the size of a molecule will still be present. The upper surface will be supported on the summits of these hills and large areas of the surface will be separated by a distance which is great compared with the dimensions of a molecule. Although the techniques of grinding and polishing have advanced in the past few years,

it is still a difficult matter to prepare surfaces of appreciable size which are flat to within a thousand angstroms.* Since the range of molecular attraction is only a few angstroms, we may expect that the area of intimate contact, that is, the area over which the surfaces are within molecular range, will, even for very carefully prepared surfaces, be quite small. A new and powerful method for studying surface irregularities and surface structure is the electron microscope, and recent stereoscopic pictures show in some detail small scratches about 250 angstroms deep on polished metal surfaces.

In general, the surfaces used in engineering practice are less flat, and the surface irregularities present on them are, in terms of molecular dimensions, enormous. These irregularities may be seen by cutting a section at right angles to the surface and examining it with a high-power microscope, but a more revealing method is to cut a section at an oblique angle to the surface. This has the advantage that it magnifies the irregularities in the vertical direction and leaves the horizontal magnification unchanged. Taper sections prepared in this way showing some characteristic contours of surfaces finely machined and also ground with abrasives of varying degrees of fineness are given in Plates 10, 11 and 12. It is seen that even with the finest abrasive, the surface irregularities are of the order of about one thousand angstroms. A molecule at the bottom of one of these pits endeavouring to establish contact with the upper surface would, on this scale, be rather like a mouse on the floor of a barn trying to touch the roof with its whiskers.

If the surfaces are polished, the effect is to cause the summits of the peaks to flow into the valleys, so that the

* The small unit of length frequently used for measuring atoms or molecules is the angstrom, which is the one-hundred-millionth part (10^{-8}) of a centimetre, or the one-250-millionth part of an inch. A copper atom is about 3 angstroms in diameter, and the range of molecular attraction is of the same order of magnitude. For somewhat larger distances, the micron is used; this is equal to ten thousand angstroms, and is therefore one ten-thousandth (10^{-4}) of a centimetre.

contour resembles rolling downs rather than rugged alpine peaks But again, the surfaces will touch only on the summits of the hills, and the area of intimate contact will be small Some knowledge of the real area of contact between solid surfaces is essential for our purpose, and its determination is a matter of some experimental difficulty. Fortunately, with metals an approximate estimate of it can be made by measuring the electrical resistance across the surface of the metals when they are in contact

If the metals touch at a number of points, the electric current will be carried across at these points, and by measuring the electrical resistance, it is possible to form some estimate of their size The results show that the real area of contact is indeed very small, it varies with the load, but for flat steel surfaces it may be less than one ten-thousandth of the apparent area. The experiments are also interesting in that they show that the real area of contact is almost independent of the size of the surfaces. It is also very little influenced by the shape and degree of roughness of the surfaces. it depends mainly on the load which is applied to them, and is, in fact, directly proportional to the load The general behaviour is consistent with the view that the surfaces are held apart by small irregularities. This means that, even with lightly loaded surfaces, the *local pressure* at these small points of contact is very high, and may be sufficiently great to cause steel to flow plastically. Although the stresses will cause elastic deformation of the metal in the vicinity of the points of contact, the experiments suggest that the summits of irregularities on which the bodies are supported flow plastically, and are crushed down until their cross-section is sufficient to enable them to support the applied load. These experiments offer an explanation of the first "law". since the real area of contact between the solids is independent of the actual size of the surfaces, we should also expect that the friction would be independent of their actual size. Also, since the real area of contact is proportional to the applied load, it offers, as we shall see later, an

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Plate 10

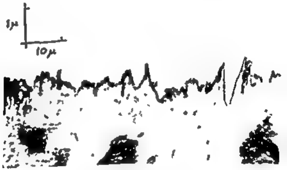


Plate 11

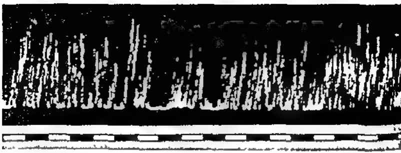


Plate 13.

Plate 14

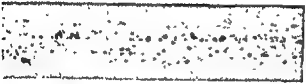


Plate 15

Plate 17

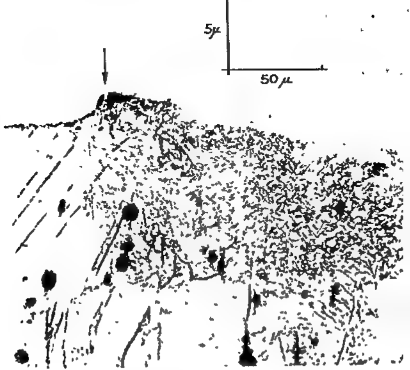
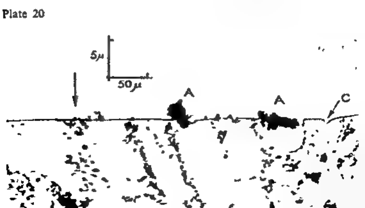


Plate 19

Plate 20

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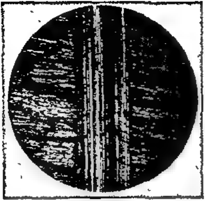

Plate 21

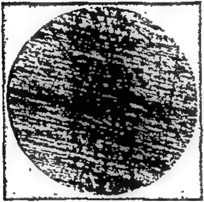

Plate 22.

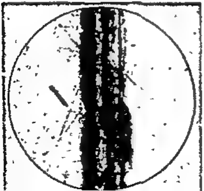

Plate 23

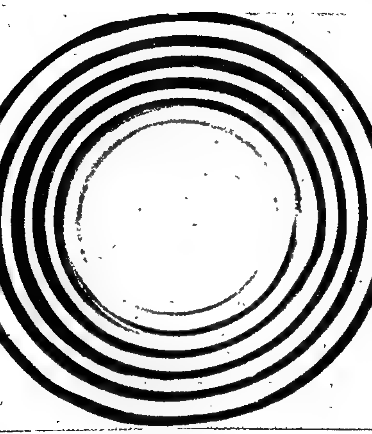

Plate 24

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CAPTIONS FOR PHOTOGRAVURE INSET

Plates 10 to 25

Plate 10 Finely turned surface of copper Vertical magnification ×1,800 Horizontal magnification ×210. The turning marks may be clearly seen. The height of these irregularities is about 50,000 angstroms

Plate 11 Steel surface ground with carborundum paper (grade 150). Horizontal magnification ×1,000 Vertical magnification ×10,000 The surface irregularities are about 3,000 to 10,000 angstroms.

Plate 12. Steel surface ground with very fine carborundum (grade 600) *Horizontal magnification ×1,000* Vertical magnification ×10,000 The surface irregularities are about 1,000 angstroms

In these figures, the ruled lines give the distance in microns (10^{-4} cms) The symbol μ is used to represent a micron.

Plate 13 Cathode ray trace of local surface temperatures with a constantan slider sliding over a finely ground steel surface Load 500 gms, speed of sliding 300 cms. per second The temperature flashes are extremely high and of a very short duration

Plate 14 Magnified chemical patterns showing the distribution of copper adhering to a polished steel surface after traversing the surface once Magnification ×15. The copper appears black.

Plate 15. The same as (14) except that the surfaces were lubricated Although the adhesion of copper to the steel is very much reduced, it is still apparent.

Plate 16. Track formed when radioactive lead is slid over a lubricated copper surface The lead which is adhering to the copper appears as white marks on the photograph Magnification ×15

Plate 17. Track formed when copper slides on copper This is at a lower magnification, but the damage is very great

and deformation of the metal again occurs to a considerable depth below the surface. Vertical magnification ×1,000. Horizontal magnification ×100

Plate 18. Highly magnified section of copper fragment (dark colour) which has welded on to the steel. Note how it has pulled the steel up *above* the surface. Vertical magnification ×500 Horizontal magnification ×500.

Plate 19 Section of track formed in copper when a small curved steel slider passes over it once The copper is ploughed out and marked deformation of the copper occurs to a considerable depth beneath the track.

Plate 20. Section of track formed on steel when a small curved slider of copper passes over it once The steel is only slightly damaged (small pits C, C) but fragments of copper (A, A, A) remain welded on to it Vertical magnification ×2,000 Horizontal magnification ×200

Plate 21 Track formed when steel slides on copper The steel slider has ploughed out and torn the copper surface Magnification ×20.

Plate 22. When copper slides on steel, the steel is scarcely damaged but fragments of copper remain adhering to the steel surface. Magnification ×20

Plate 23 Track formed when nickel slides on nickel The damage to the surface is very heavy Magnification ×20.

Plate 24. Photographic record of hot spots produced by a steel surface sliding on a rotating glass plate (Load 1,200 gms.). The outermost track corresponds to a sliding speed of 150 centimetres per second. The innermost track represents the lowest speed at which the hot spots are recorded on the photographic plate. Under these particular conditions, it was 67 centimetres per second.

Plate 25. Professor Haldane (centre) listens to the pressure chamber, during a test on human subjects (see pp. 12 *et seq*)

explanation of the second "law" The fact that the real area of contact is so small has important practical implications. Even when loads of only a few hundred grammes are applied to the surfaces, the local *pressure* between them may be sufficiently great to cause the flow of metal When large flat surfaces are used, it does not mean that the real pressure is much less, but merely that the points of contact are more widely distributed.

As we shall see later, this intense pressure may cause an actual welding together at the tiny points of contact, and so produce small metallic junctions between the surfaces The pressure between the surfaces in the regions where contact occurs is determined primarily by the flow pressure of the metal itself It is interesting to note that even when the surfaces are lubricated with a boundary film of a good lubricant, similar conditions hold The load will again be carried by the surface irregularities, and even for light loads, the local pressure on the lubricant film will be very high In the case of mild steel, for example, it may be about 100 tons per square inch Unless the lubricant molecule possesses an "active group" capable of attaching it firmly to the surface, the local high pressure will force it from underneath the points of contact In this sense all good lubricants must act as "extreme pressure" lubricants.

Let us now consider in more detail the physical processes that occur when we set these solids in motion and cause one to slide over the other The frictional resistance occurs, of course, over the small localised regions where the solids are actually in contact, and we will enquire into its mechanism

The Surface Temperature of Rubbing Solids

The energy lost during sliding is dissipated mainly in the form of heat, and the second query is, what will be the temperature of the surfaces? Quite primitive calculations of the amount of heat which is liberated and of the rate at which it is conducted away suggest that the temperature rise of the surface layers may be high If we endeavour to

measure this by embedding thermometers in the solids near the surface, we find that the rise is very small, but this is mainly because we cannot get close enough to the surface. An obvious method is to use the surfaces themselves as a thermometer. If two different metals are placed in contact, and the junction is warmed, an electromotive force* is generated. The metals form what is called a "thermocouple," and a measurement of the electromotive force can be used to determine the temperature of the metal contact. We may therefore make our sliding surfaces of two different metals, and use the rubbing contact itself as a thermocouple. A measurement of the electromotive force generated on

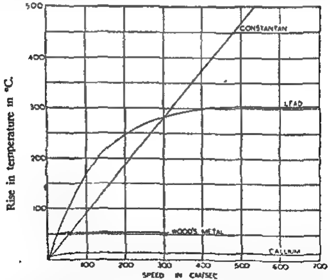

Fig 16.—Maximum temperatures reached when small cylinders of gallium (Melting point 32° C.), Wood's alloy (Melting point 72° C.), lead (Melting point 327° C.) and constantan (Melting point 1,290° C.) are slid on a steel surface. The maximum temperature does not exceed the melting point of the metal.

* See Glossary

sliding them provides a record of the surface temperature. It is apparent that the electrical contact and the friction occur at the same points where the surfaces touch, so that the measurement gives information about the temperature of the surface layer of the metals where they are rubbing.

Such measurements confirm in a very striking way the existence of local high temperatures at the points of contact of the rubbing surfaces. As would be expected, the temperatures reached depend upon the load, the speed of sliding and the heat conductivity of the metals. Also the temperatures fluctuate very rapidly during sliding, and it is necessary to use an instrument of high frequency, such as a cathode ray oscillograph or high frequency galvanometer, in order to record them. Fig 16 shows the maximum temperature reached when small cylinders of gallium, which melts at 32° C., Wood's alloy, which melts at 72° C., lead, which melts at 327° C., and constantan, which melts at 1,290° C., are slid on a steel surface.

It will be seen that with the lower melting metals, we readily reach their melting point, and the temperature does not rise above this. With constantan, temperatures of the order of 500° C. to 1,000° C.* are reached. These temperatures are confined to the very thin surface layer, and the mass of the metal appears to be quite cool. The rapid and intense nature of the temperature fluctuations is shown strikingly in the cathode ray trace given in Plate 13. It will be seen that the very high-temperature flashes of 1,000° C. may last only for a few ten-thousandths of a second.

It is interesting to note that if the surfaces are flooded with water, the local high temperatures may still occur. If the surfaces are lubricated with a boundary film of good lubricant, the surface temperatures are greatly reduced, but the experiments show that localised metallic contact may still occur through the film, and the surface temperature at the summits of the surface irregularities may still be sufficiently high to cause volatilisation and decomposition of

* 1,000° C. is equal to about 1,832° Fahrenheit.

the lubricant film If the sliding solids are poor conductors of heat, the frictional heat generated at the surface cannot get away so rapidly, and we should expect that high surface temperatures would be reached more easily. With non-conducting solids, such as glass or quartz, the heat conductivity is very low compared with that of metals; with glass, for example, the heat conductivity (k) is 0.002 With such solids we should expect, therefore, that local hot spots would occur much more readily

Unfortunately, the thermocouple method cannot be used with these solids, but it is possible to show the existence of these hot spots by visual means If polished surfaces of glass or quartz are used, and the apparatus so arranged that a clear image of the rubbing surfaces can be seen, it is found that, if the sliding is carried out in the dark, a number of tiny stars of light appear at the interface between the rubbing surfaces. The points of light are reddish in colour at low speeds, and become whiter and brighter as the speed or the load is increased It is clear that they correspond to small hot spots on the surface, and their position and distribution over the surface change from instant to instant as the high points in intimate contact move or wear away, and new points come into contact. The method is not quantitative, but by making one of the surfaces of metal, and using metals or metallic alloys of different melting point, it is possible to fix approximately the temperature at which hot spots first become visible. Experiment showed that when metals or alloys melting *below* 520° C. were slid on glass or quartz, no hot spots could be seen even at the highest speeds and loads With a gold-aluminium alloy melting at 570° C., however, and with all metals melting *above* this, the hot spots were readily seen This would fix the temperature at which the hot spots first became visible to the eye, at between 520° and 570° C. This temperature of a little over 500° C is about the same as that of a poker which has been placed in the fire and is glowing a dull red.

A series of experiments was carried out with metal of different heat conductivity sliding on a glass disc. The sliding speed was kept constant, and the load varied until hot spots first became visible At the same time, the coefficient of friction was measured so that the frictional force necessary to give hot spots (at any given speed) could be determined The results obtained for sliders of constantan (k=0 05), steel (k=0 10), nickel (k=0.16) and tungsten (k=0 35) are shown in Fig 17. It will be seen that hot spots occur more readily the lower the heat conductivity of the slider For example, at a surface speed of 110 cm./sec., tungsten, which is a good heat conductor, sliding on glass gives visible hot spots when the frictional force is 2,600 gms, while with constantan, which is a relatively poor heat conductor, hot spots can be seen when the frictional force is only 350 gms

If the surfaces are flooded with a liquid (e g, with a mixture of glycerine and water), the hot spots still occur, and the results for metals of varying heat conductivity are similar to those given in Fig. 17. The main difference is that all the curves are shifted upwards, and a higher frictional force (six to seven times as great) is necessary to produce hot spots when the surfaces are flooded. This difference is considerable, but it is clear that the presence of the liquid film is not able to prevent the occurrence of high local temperatures

Although the occurrence of a transient hot spot is readily observable, the intensity is usually too low to affect a photographic plate If, however, the slider is run over the same track a number of times, the cumulative light from the hot spots is enough to produce a record. A sensitive photographic plate was held in a frame mounted on the turn-table. A glass disc was clamped over it, and the metal slider rested on top of this glass disc. A given load was applied, the turn-table was rotated at constant speed, and the slider allowed to run for two minutes on the same track. It was then moved in, about a centimetre, towards the centre

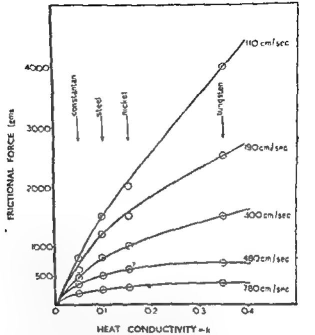

Fig 17.—Frictional force (in grammes) necessary to give visible hot spots with sliders of constantan ($k=0{\cdot}05$), steel ($k=0{\cdot}10$), nickel ($k=0{\cdot}16$) and tungsten ($k=0{\cdot}35$)

of the disc and again ran for two minutes The process was repeated, and in this way a series of concentric tracks was obtained, of decreasing radii and therefore of decreasing sliding speeds On developing the photographic plate a number of concentric dark rings appeared (see Plate 24) The innermost visible ring on the plate gave the lowest sliding speed at which hot spots were recorded. The results obtained with this technique were very similar to those obtained by visual observation of the hot spots. The effect of thermal conductivity was the same (the curves obtained closely resembled those given in Figure 17 and the actual

values of the minimum loads and speeds necessary to give detectable hot spots were very similar)

For any given combination of surfaces, the incidence of hot spots is determined primarily by the rate of liberation of frictional heat, *i e*, by the product of coefficient of friction multiplied by load times speed It is not greatly influenced by the size and shape of the slider If a large flat slider is used, the conditions of load and speed necessary are much the same as for a small curved one The main difference is that with large flat surfaces, the hot spots may be thinly distributed over a wide area instead of being concentrated into a smaller one This is in harmony with the view that contact between the solids occurs only locally at the summit of the surface irregularities, so that the real area of contact is very small and bears little relation to the apparent area of the surfaces It means that even with light loads, the pressure at the points of real contact is high, and it is just at these points that the rubbing and the liberation of frictional heat occurs. It is, of course, common knowledge that if surfaces are rubbed hard enough they get hot, but a point brought out by these experiments is that the loads and speeds necessary to give red hot spots are very low. For example, with a metal sliding on glass with a load of a few pounds, visible hot spots (temp. 520-570° C) can be seen when the sliding speed is as low as one or two feet per second If the upper slider of metal is replaced by a poor heat conductor such as quartz (k=0 0035), the hot spots appear even more readily.

Experiment has shown that these local hot spots are important in a number of physical processes associated with the rubbing of solids, such as the polishing and surface flow of solids, the seizure of metals, the "frictional welding" of plastics and other materials They also play an important part in the chemical decomposition which accompanies the rubbing of some solids, and in the initiation of chemical reactions which are brought about by friction and by impact An interesting example of this is the initiation of some

explosions by friction. Experiments with nitro-glycerine, for example, rubbed between metal surfaces show that the load and speed necessary to cause initiation is determined primarily by the heat conductivity of the sliding metals. With a poor heat conductor, such as constantan, initiation occurs more readily than with a good conductor, such as tungsten It is also found that, unless the melting point of the metals exceeds 480° C., explosion of the nitro-glycerine does not occur even at very high loads and speeds. The initiation of the explosive is brought about by local hot spots on the surface of the rubbing solids.

Before considering the bearing of these results on friction, we may enquire what part this localised heating plays in the polishing of solids

Polishing and the Surface Flow of Solids

The usual method of polishing surfaces is to rub them together with a fine powder between them By this process, a rough surface having visible surface irregularities is changed into one where the irregularities are invisible If the polished surfaces have a mirror finish, the height of these irregularities will be less than half a wave length of visible light, *i.e.*, less than 2,000 angstroms. The classical work on polishing is that of Sir George Beilby, who showed that the top layer of the polished solid is different in structure from that of the underlying layers It has lost its obvious crystalline properties and has apparently flowed over the surface, bridging the chasms and filling up the irregularities in it The mechanism of the process has been a subject of discussion for many years. Newton, Herschel and others considered that polishing was essentially due to abrasion, that is, to a gradual wearing away of the surface irregularities. on Beilby's view it was due to some surface tension effect. As we have seen, however, the frictional heat generated at the rubbing surfaces may easily raise the temperature to a high value, and this suggests that the local heat

softening or actual melting may play an *important* part in the polishing process.

The action of a typical polisher may be represented diagrammatically as in Fig 18 The polishing particles of rouge or alumina are embedded in a block of pitch and rubbed on the specimen in the presence of a liquid such as water At the points of rubbing contact between the polishing powder and the specimen, hot spots will occur, which will cause a local surface softening or melting of the specimen. The melted or softened solid will be smeared over the surface and will quickly solidify to form the Beilby layer

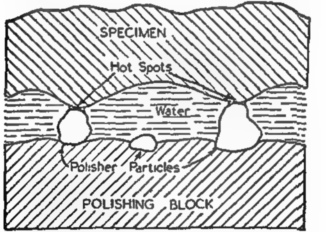

Fig 18—Diagrammatic representation of a typical polisher

We may perform a simple experiment to test this hypothesis. If polishing is due primarily to a mechanical abrasion and wearing away of the specimen, we may expect the relative *hardness* of the specimen and of the polisher to be of major importance If, however, it is due to surface melting it is the *relative melting point* which will be the

determining factor If the polisher melts or softens at a *lower* temperature than the specimen, it will melt or flow first and will have comparatively little effect on the specimen.

The experiment was tried of rubbing Wood's metal (Melting point 72° C) with a camphor block (M.P. 178° C.). Although the Wood's metal is very much harder than the camphor, it melts at a lower temperature, and it was found that surface flow and polishing of the alloy readily occurred On the other hand, camphor would not polish tin (M.P. 232° C.), lead (M.P. 327° C), white metal (M P. 233° C.) or zinc (M P. 419° C.), which melt at a higher temperature than the camphor. A polisher using a powder of oxamide (M.P. 417° C.) readily caused flow of all these metals but did not produce any effect on speculum metal (M.P 745° C.) or copper (M.P. 1,083° C) which melt at temperatures well above 417° C Lead oxide (M P. 888° C.) polished speculum metal and all metals melting below it, but had little effect on nickel and molybdenum, which melt above it. These in turn were readily polished by the high-melting oxides such as chromic oxide or stannic oxide. Similar results were obtained with glasses, quartz and some non-metallic crystals, calcite (M P 1,333° C.), for example, showed no flow on cuprous oxide (M.P. 1,233° C.) which melts a little below it, but was readily polished by zinc oxide (M.P. 1,850° C.) which melts above it It is well known that the mechanical strength of many metals and solids falls to a very low value at temperatures well below the melting point, so that they lose their rigidity and resistance to shear at comparatively low temperatures. For such solids, surface flow would be expected to take place at temperatures well below the melting point and experiment shows that, in many cases (*e.g.*, gold) this can occur. The rate of flow and polish is, however, very much less and may take hours, instead of the few minutes required by a high melting polisher.

The experiments provide strong evidence, not only that high local temperatures occur, but that they play a large

part in the process of polishing. In many cases the frictional heat will raise the temperature to a sufficiently high value to cause a real melting of the solid at the points of sliding contact The molten solid will flow or will be smeared on to cooler areas, and will very quickly solidify to form the Beilby layer Polishing under these conditions is rapid. If the sliding is gentle or the melting point of the polisher is low, the surface of the solid may not reach the temperature of melting. Polish and surface flow may still occur under these conditions, provided the temperature reaches a point at which the mechanical strength of the solid is sufficiently low for it to yield under the applied stress or under surface tension forces. Polishing under these conditions is a slow process. The relative hardness of solid and polisher as normally measured at room temperature, is comparatively unimportant This is shown clearly in the case of Wood's alloy and tin on camphor, or speculum metal and nickel on lead oxide The harder metal of low melting point is polished, while the softer metal of higher melting point hardly flows at all Similarly, zinc oxide, which is comparatively soft, but has a high melting point, readily polishes hard quartz, which melts at a lower temperature The amount of surface flow is governed, not by the properties of the solids at room temperature, but by their relative mechanical properties at the high temperature of the sliding surfaces

The Mechanism of Sliding on Ice and Snow

Another phenomenon where surface melting may play a part is in the sliding of solids on ice and snow—in skating or skiing. It is well known that the friction under these conditions may be remarkably low (the coefficient of friction is 0.02 to 0 03). The suggestion has often been made that in skating or skiing, the surfaces are lubricated by a layer of water formed by pressure-melting, but few experiments have been made to support or to disprove the suggestion

Ice is a peculiar solid, in that its volume is greater than that of the water from which it is formed. With many other solids the converse is true, they "shrink" on freezing. The fact that water expands on freezing means that if pressure is applied to the ice, it will tend to melt. With the other class of solids, the application of pressure would only encourage it to freeze harder. The lowering of the melting point of ice with pressure is not very great; applying an additional pressure of one atmosphere (14 lb. per sq. in.) will cause ice to melt at -0.0075°C. instead of at 0°C. Experience shows that skis slide quite readily on snow at -20°C. Calculations of the pressure necessary to cause melting at this low temperature suggest that it is unlikely that it would be attained. On the other hand, calculations of the amount of heat liberated by frictional heating as the ski moves forward a small distance show that it is sufficient to warm up the snow and to melt an appreciable water layer. There is much to be said for turning one's work into a holiday, and some experiments were carried out at the Jungfraujoch in Switzerland, to determine whether a water layer is formed at all, and if so, whether it is due to pressure-melting or to frictional heating. Measurements of the electrical conductivity between metallic electrodes on the bottom surface of miniature skis sliding on salty ice indicated that at low temperatures the surface melting occurred only at localized areas, but at temperatures near 0°C. a continuous water film was formed on sliding.

The effect of temperature on the friction of different solids sliding on ice surfaces is shown in Fig. 19. It will be seen that the friction increases markedly as the temperature falls and at a temperature of -140°C. it is some five or six times as great as it is at 0°C. The value for the coefficient of friction (0.1) at these low temperatures is of the same order of magnitude as that observed on other crystalline solids such as calcite. The large influence of temperature on the friction of ice is in marked contrast to the behaviour

of most other solids where temperature has only a small influence. It emphasises the anomalous behaviour of ice and supports the view that the low friction is due to a lubricating water layer As the temperature falls, it becomes increasingly difficult for a water layer to be formed and the friction rises.

It is of particular interest to determine the influence that the heat conductivity of the ski has on the friction at low temperatures. If sufficient pressure is applied to the ice to lower the melting point to the actual temperature of the ice it is, of course, capable of melting. An appreciable quantity cannot melt, however, unless heat is supplied from some source at a temperature higher than the pressure melting point equilibrium. Both the heat capacity of the ice and its heat conductivity are small, and this heat can most readily be supplied from some outside source If the temperature of the atmosphere is higher than either of the ice surfaces, it could be supplied by conduction from the air. Under these conditions, we should expect that the friction of a good heat conductor would be less than that of a bad one. The friction of a brass ski on cold ice should be *less* than that of an ebonite one. If, however, the lubricating film is formed by frictional heating, the converse will be true. The frictional heat is liberated at the interface between the sliding surfaces, and if the ski is a good heat conductor, the heat will be carried away rapidly and less will be available for surface melting. On this view, the friction of a brass ski on cold ice should be *greater* than that of an ebonite one Fig 10 shows the results obtained using a miniature ski of brass and one of ebonite.

At temperatures near 0°C. the frictions of both skis were the same At lower temperatures, however, the results showed that the friction of the brass was considerably greater than that of the ebonite. The lower the temperature, the more pronounced this difference usually became. These results provide evidence that the frictional heating plays an important part in the formation of the water film

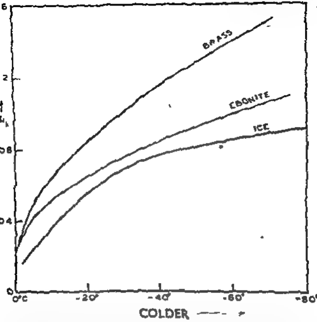

Fig 19—Effect of temperature on the friction of brass, ebonite and ice sliding on ice The friction increases markedly as the temperature falls, and is lower for the slider possessing the lower heat conductivity.

The observations have an interesting bearing on sledging and skiing No quantitative measurements of the friction of sledges seem to have been published. but there is general agreement that the friction increases at low temperatures. Many Arctic explorers have recorded that at very low temperatures, —30°C. to —40°C., the friction between the snow and the runners became so great that the sensation was that of pulling a sledge over sand. Wright, summarizing the conclusions of the Scott Polar Expedition of 1911-13, says. "Quite apart from any question of the hardness of the snow, however, the surface temperature has an important influence Our opinion was that the friction

decreased steadily as the temperature rose above zero Fahrenheit (—18°C.), the presence of brilliant sunlight, having an effect, which was more than a psychological one, on the speed of advance Below zero Fahrenheit (—18°C.) the friction seemed to increase progressively as the temperature fell, as if a greater and greater proportion of the friction were due to relative movement between the snow grains and less to sliding friction between the runner and snow." This steady increase in friction as the temperature of the ice or snow falls, is clearly shown in Fig. 19

It is probable that below —40°C very little surface melting occurs under these conditions On the return journey from the Pole, Scott's party struck particularly cold conditions, and it is probable that the high friction of this very cold snow contributed materially to the final tragedy

The influence of the thermal conductivity of the sliding body on the friction, shown in Fig. 19, is also borne out by practical experience It will be seen from this figure that at low temperatures the friction of a good heat conductor is considerably greater than that of a poor one. Nansen, in 1898, compared two sledges, one having nickel-plated metal runners and the other maple runners The temperature was low—the actual value is not given, but the mean temperature during that month was —36 8°C. (—34 2°F.). He found that the friction of the metal was higher: "The difference was so great that it was at least half as hard again to draw a sledge on the nickel runners as on the tarred maple runners."

The heat conductivity is also important in ski-ing Nowadays, most skis are fitted with brass or steel edges, although sometimes vulcanite or plastic edges are used. The friction measurements show that the latter should be faster at very low temperatures. If metal must be used, one of low thermal conductivity such as German silver or constantan should be better on very cold snow.

The Chemical and Radioactive Detection of Metal picked up during Sliding

When the surfaces are lubricated, the metallic interchange between the surfaces is very greatly reduced, so that its detection, even by the taper section method, is difficult. It may, however, be detected in the following way. A gelatine-coated paper is soaked in a suitable electrolyte and pressed, while still wet, against the surface to be examined. A small current is passed between the paper and the metal, so that the metallic ions pass into the gelatine. As they are prevented from diffusing by the gelatine, the ions concentrate in a pattern corresponding to their distribution on the metal surface. By means of a sensitive colour reagent, the distribution of ions in the gelatine can be shown up. The results obtained with copper sliding on an unlubricated steel surface are shown in Plate 14 The copper slider has passed over the steel surface once. The track widths are magnified 15 times, and the black markings show the presence of copper It will be seen that the pick-up of the copper on the polished surface is fairly random with a tendency to be arranged in lines parallel to the track. These would correspond to high spots on the copper contact as it is worn down.

Under lubricated sliding, the same effects are noticed but to a much smaller degree (see Plate 15). It is apparent from these pictures that marked pick-up of copper can occur under both clean and lubricated conditions, and that it occurs more readily at the high spots of either of the two sliding surfaces. This method is extremely sensitive and it is probable that the amount of copper on the surface of the lubricated steel is less than a millionth of a gramme per square millimetre.

A still more sensitive method is to use a radioactive metal as one of the sliders and detect the presence of any picked-up metal either by a Geiger counter or by placing a photographic plate in contact with the surface. The radiation from the radioactive metal fogs the photographic plate, and so enables

its *presence to be detected* By these methods, quantities of less than the one-thousand-millionth (10^{-9}) of a gramme can be detected, and the results again show that minute junctions of welded metal are formed through the lubricant layer. A photograph showing the adhesion of a radioactive lead to a lubricated copper surface is given in Plate 16

Theory of Solid Friction

There have, in the past, been two main theories of solid friction. According to the first, friction is due simply to a mechanical interlocking of the surface asperities on the solids, the frictional work would then be the work of lifting the slider over these asperities According to the second, it is due to a *molecular attraction between the two solids* and should be explicable in terms of surface forces It is clear, however, from these experiments that the physical processes which occur during sliding are very complex, although to the naked eye, or even to the high-power microscope, there may appear to be little change, yet, on a molecular scale, an enormous tearing, welding and deformation has taken place. If the sliding is continued, this ultimately becomes manifest as wear, or perhaps as a seizure of the surfaces. Friction cannot be regarded simply as a surface effect. Penetration and distortion occur to a great depth beneath the surface, and the frictional force and the nature of sliding are both influenced by the bulk properties of the solids The physical *properties of the solids such as their relative hardness and* (if the sliding speed is high) their relative melting point play an important part.

Experiments suggest that the frictional resistance between unlubricated metals is due primarily to the shearing of the small metallic junctions formed locally by pressure welding and by adhesion at the points of contact, and to the work of dragging or ploughing the surface irregularities of the harder metal through the softer one, so that we may write the frictional force F as

$$F=S+P$$

loads, since it is not greatly affected by the plastic deformation of the hard metals; it is determined essentially by the thickness of the film and the shape of the surfaces.

Experiments carried out with very thin films of lead and indium deposited on the surface of a hard metal show that the friction is indeed very low. Indium is a metal which is softer even than lead, and if films of this metal a few hundred atomic layers in thickness are deposited on hard steel, the coefficient of friction under heavy loads may be as low as 0.04; that is, it may be comparable with the friction of ice. Lubrication by thin metallic films plays an important part in the action of many bearing alloys. For example, one bearing "alloy" which is now widely used, consists of copper with tiny particles of lead distributed through it. When rubbing takes place, a thin film of lead is smeared over the surface of the copper, and reduces the friction and wear between the bearing and the steel shaft. For another type of bearing, silver is used with a thin film of lead or of lead and indium deposited on its surface. These were the kinds of bearing which proved so effective in our Spitfires, and in many of our heavy bombers during the war.

The lubrication of metal surfaces with an oil or with grease is an analogous process in so far as it consists in covering the metal with a surface layer of low shear strength. Whether we deliberately add a lubricant or not, most solid surfaces are coated with a film of some kind. However carefully we clean, or polish, or scrape them, there will, if we conduct the operation in air, still be a thin film of oxide or other contaminant adhering to the surface. It is very difficult indeed to remove the last trace of the contaminating film, and to maintain the surfaces clean. With some metals, for example, it may be necessary to heat them white hot in a high vacuum before the last trace of oxide can be driven off the surface. If this experiment is carried out, and measurements made on really clean metals, it is found that there is a very great increase in the friction. The coefficient of friction between really clean metals is greater by a factor

of ten or more than it is with surfaces "cleaned" in the ordinary way, and the metals seize under the slightest loads This observation that the friction of naked solids is very high, makes us realise how fortunate it is that, in engineering practice and, in fact, in many everyday affairs, metals and other surfaces are always contaminated even when we think we have cleaned them thoroughly If it were not for this, we would find the world a very sticky place to live in, and much of our machinery would come to a sudden and disastrous stop

GLOSSARY

Conductivity, Coefficient of Heat flows at different rates along bars of different materials A metal saucepan handle, for instance, gets untouchably hot long before a wooden handle under the same conditions A number, or coefficient, can be given to each material to express this conduction of heat, in order to compare one stuff with another precisely The number is the amount of heat (in calories) flowing through each square centimetre of material per second, when the temperature drops one degree centigrade for each centimetre along the material away from the source of heat

Cordite An explosive composed of gun-cotton (nitro-cellulose) and nitroglycerine

Electrolyte: A substance capable of conducting electricity when dissolved in water; usually a salt.

Electromotive Force (E M F): When an electric current flows along a wire it is capable of doing a certain amount of work, for instance, ringing an electric bell, and this ability or electromotive force depends on the strength of the current and the resistance of the wire (Ohm's law) It is measured in Volts

Electroscope An instrument for detecting the presence of electricity

Harmonics In music, these are the overtones to any musical note. Each note represents so many vibrations (or waves) per second in the air, and each harmonic is some multiple of the fundamental vibration In other words, air, water, etc. can vibrate or oscillate with more than one frequency at once, and the complex oscillations produced are called harmonics

Infra-Red When light passes through a prism it spreads out in all the colours of the rainbow—red, yellow, green, blue, violet These are the visible colours, the only part of the spectrum to which the eye is sensitive But beyond the violet, there is still light, the "ultra-violet," which some insects can perceive though we cannot Likewise before the red, there is light which can mark a special photographic film, though dark to us—the infra-red Part of the infra-red light we perceive in another way, namely as heat

Ion: An atom or molecule carrying a charge of positive or negative electricity, and therefore moved in one direction by an electric current, as in electrolysis Ions of the same charge repel, of different charges (one positive, the other negative) attract one another

Isotherm. A line drawn on a map to connect all the places having the same temperature on a particular occasion.

PARTICLE: There are various atomic fragments described in modern physics, viz.:

A—Positively charged particles

Alpha particle (the doubly positively charged nucleus of a helium atom)

Proton (the nucleus of a hydrogen atom, also called a hydrogen ion)

Positron (a positive electron, 1/1850 mass of a hydrogen atom).

Meson (from cosmic rays, 1/1000 mass of a hydrogen atom)

B.—Negatively charged particles

Electrons (also termed beta rays)

Mesons

C—Neutral particles

Neutron (same mass as proton, 10^{-24} gram)

Neutrino (same mass as an electron)

A photon is a "grain of light," the smallest possible amount (or quantum) of light energy which can be emitted, transmitted, or absorbed.

A nucleon is a general name for any component of the atomic nucleus (proton or neutron)

SILICEOUS SKELETON Silica, the oxide of the metal silicon which is a component of some steels, occurs naturally as quartz and sand, and forms the skeleton of some tiny marine living things, called diatoms

SPECULUM METAL An alloy, two parts copper to one part of tin

SPECTROSCOPE An apparatus for studying the spectrum in detail. (See *Infra-red*.) Through it the light given off by sodium vapour (the orange-yellow electric street lamps) appears as two thin yellow lines close together in the yellow part of the spectrum. The light given off by mercury vapour street lamps shows thin lines of colour in red and green, as well as a number in the blue-violet

SYNOVIAL FLUID Most joints in the body are moistened or "oiled" inside with a little colourless fluid, derived from the blood.

ULTRA-VIOLET: See *Infra-red*, supra

VISCOSITY, COEFFICIENT OF A number which describes the relative stickiness of a fluid; thus treacle is more glutinous than water, and water than methylated spirits, which thus has the smallest number (coefficient) of the three. A measure of the resistance to pouring out.

VOLATILISATION: When a solid changes readily into a gas or vapour, without first melting to a fluid. Sal volatile is a common example of this phenomenon

INDEX

Age, evidence of human, 40
Air, phenomena in compressed 16, 17
Angstrom, meaning of, 142
Appleton layer, 55
Area of contact between solids, 141

Beilby layer, 151 *et seq*
Bends, 24
Blood grouping, 49
Bohr's atom, 122

Cordite, 30
Creep strength of metals, 35

Davis escape apparatus, 12, 27
Diabetes and tuberculosis, 107
Diving dress, 10 *et seq*
Double tides, 93

Eustachian tubes in diving, 14
Explosions, initiation of, 151

Fingerprints, 39, 46
Firearm identification, 45
Forgery detected by infra-red, 42
Fruiting, stimulus to, 137

Gauss, meaning of the unit, 116

Heaviside layer, 55
Hot spots in friction, 147 *et seq*

Ice, properties of, 155
Indium, lubrication by, 165
Industrial health research, 29
Ionosphere, 55

Leaf fall, control of, 137
Lubricants and lubrication, 144 146, 165

Micron, meaning of, 142

Neutrino and neutretto, 123
Nitrogen as narcotic, 20
North Atlantic deep current, 87

Oxygen poisoning, 20 *et seq*

Paint analysis by spectroscope, 43
Photographic plate for atomic research, 123
Photoperiodic induction, 131
Photosphere of Sun, 54
Phytoplankton, 99
Pneumothorax, 15
Polishing, the nature of, 151
Pressure under the sea, 9

Radioactive lead transferred on sliding, 162
Radio fade-out, 57

Scott Antarctic expedition, 157
Sex, and stature, evidence of, 40
Skiing, investigation of, 155
Sledging, 158
Sounding the sea depths, 78
Strangling, 41
Sunspots, behaviour of, 56
Surface flow of solids, 153

Teeth, evidence from, 40
Temperature of the sea, 81 *et seq*
Temperature on sliding, 146
Tuber formation, factors in, 137

Vitamin B, function in the brain, 64

Wave spectrum, 96
Welding, by heat of friction, 150

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" Acknowledgments are due to Messrs Chapman and Hall for permission to reproduce Plate 5, and to Dr. Martin for permission to reproduce plate 6 "

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